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Founders of Seismology.—III. John Milne.

By Charles Davison, Sc.D.

DURING the period of about ten years which included that of Mallet's death—say, five years before and five after—the study of earthquakes made rapid progress. Among the more prominent contributors were M. S. de Rossi and G. Mercalli in Italy, F. A. Forel and A. Heim in Switzerland, E. Suess in Austria, J. F. J. Schmidt in Greece, T. Oldham in India, and C. G. Rockwood and C. E. Dutton in the United States. Their work, however, was mainly carried out on the old lines. For the introduction of new methods of study and of a new spirit infused into seismology, we are indebted to the small band of early British teachers in Japan, to J. A. Ewing, T. Gray, and, above all, to J. Milne. In the new epoch, now opening, when seismology demanded the whole energy of its supporters as well as their active co-operation, it is not, I think, too much to claim that Milne lifted the science to an altogether different and higher plane.

To readers of the Geological Magazine, the details of Milne's life are well known, and may here be passed over rapidly. He was born at Liverpool on 30th December, 1850, and received his training as a mining engineer under Warington Smyth at what was then the Royal School of Mines. After a few years of travelling (in Newfoundland, Labrador, and Arabia), he was appointed in 1875 to the professorship of geology and mining in the Imperial College of the Public Works Department at Tokyo. Travelling overland, he reached Japan early in 1876, his first night in Tokyo giving him an introduction to Japanese earthquakes.

For the next four years the direction of Milne's study was undecided. Then, on 22nd February, 1880, there came the strong earthquake which wrought so much havoc in Yokohama, and from this time onward his attention hardly wavered from seismology. On his initiative a public meeting was called, which resulted in the foundation of the Seismological Society of Japan, with J. Hattori as president, and himself as vice-president and secretary. For twelve years the Society flourished, coming to an end in 1892, when its work was continued and extended by the Imperial Earthquake Investigation Committee. The *Transactions* of the Society, of which sixteen volumes were published, then merged into the *Seismological Journal of Japan*, four volumes being issued from 1893 to 1895. In the latter year Milne left Japan, the close of his residence being

unfortunately marked by the burning of his library and seismological observatory. He reached England in July, and, with his Japanese wife, made his home at Shide Hill House, near Newport, in the Isle of Wight.

From 1880 onwards Milne's work was aided by grants from the British Association. The reports which he wrote as secretary of the Committee on the Earthquake Phenomena of Japan contain useful summaries of the work which he carried out in that country. At the first meeting of the Association (1895) after his arrival in England this committee and the Earth Tremors Committee were merged into the Seismological Committee, Milne continuing to act as secretary until his death, after a short illness, on 31st July, 1913.

Though Milne contributed most of his work to scientific journals, he wrote two well-known volumes on *Earthquakes* (1886) and *Seismology* (1898) for the " International Scientific Series ". Of the twenty volumes of *Transactions* and *Journal* published in Japan, he was the author of not less than two-thirds. He wrote fifteen reports of the Committee on the Earthquake Phenomena of Japan, and the greater part of eighteen reports of the Seismological Committee,[1] in addition to many other papers in various journals.

Milne differed from Michell and Mallet in his preference for co-operating with others. He was not a solitary student. Retaining to the last the cheerfulness of youth, gifted with an abiding sense of humour, kindly and hospitable, possessing not only enthusiasm but also the power of kindling in others the same eagerness, abounding in energy and loving hard work, Milne was admirably adapted—no man better—to act as a founder of the now widening science of seismology.[2]

The chief difficulty in summarizing Milne's work is its wide extent and range. Michell wrote but one memoir. Mallet's work, though it covered about sixteen years of an active life, was described in less than twenty papers and one book. Milne penetrated into nearly every corner of seismology, and his papers, if collected, would fill many volumes. I will endeavour to group his work under various headings, but to do this within a limited space minor details must be omitted, and a strictly chronological order to some extent abandoned.

Investigation of Earthquakes.—Milne was a student of earthquake phenomena rather than of earthquakes, and the strong shock of 1880 is the only one that he can be said to have investigated. At this early date the disadvantages under which he worked were great. The Japanese public were not then educated in the observation of earthquakes. De Rossi's first scale of seismic intensity was devised in 1874, but it was probably unknown outside Italy. Milne had therefore to depend on observations of the time and direction of the

[1] In the following pages these will be referred to as *Trans.*, *Journ.*, and *Rep.*, respectively.

[2] For the above biographical details I am indebted chiefly to articles in the Geol. Mag., 1912, pp. 337–46 (with portraits), *Proc. Roy. Soc.*, vol. 89, 1914, pp. xxii-xxv ; *Bull. Seis. Soc. America*, vol. 2, 1912, pp. 2–7.

shock, the latter alone being found to possess any value. These enabled him to fix the position and form of the epicentral area. To determine the depth of the focus he measured seven angles of emergence at Tokyo and Yokohama from the horizontal and vertical motions given by various instruments, and concluded that the most probable of the resulting depths are from $1\frac{1}{2}$ to 5 miles. Two other subjects on which Milne collected many observations were also considered—the rotation of chimneys and gravestones and the nature of the damage to buildings. In the Yokohama cemetery, for instance, the gravestones are arranged in parallel rows, and the stones were rotated in one direction only. This uniformity of rotation is clearly inconsistent with the explanation given by Mallet, and Milne preferred one suggested to him by his colleague T. Gray. The other subject, then and afterwards, was constantly before Milne's mind, and in this paper we see his first attempt to provide rules for the construction of earthquake-proof buildings.

Under this heading may also be included the paper on the Peruvian earthquake of 9th May, 1877, though it refers mostly to the sea-waves which were propagated across the Pacific to the coasts of Japan. The position of the epicentre was ascertained from observations on the time of occurrence, and one of the chief conclusions of the paper is that the mean depths, calculated from the measured velocities by means of the formula $v = \sqrt{(gh)}$, are less than those obtained from soundings. Milne suggests that the figures obtained from soundings may be excessive, but it was afterwards shown that the inequality observed must result from variations in the depth of the ocean.[1]

Construction of Seismographs.—Looking back after an interval of thirty or forty years it would seem that the chief debt that we owe to the Seismological Society of Japan is the construction of accurately recording seismographs. In the designing of these instruments the larger share fell to J. A. Ewing and T. Gray, the former being responsible for the invention of the horizontal motion seismograph (1880) and the duplex pendulum seismograph (1882), and the latter for that of the vertical motion seismograph (1881). To Milne we are indebted for the testing of the various instruments and for many improvements in detail. Probably no other seismologist has had so wide an experience as Milne of the seismograph in all its different forms. He wisely began with the simple apparatus in use at Comrie forty years before, and with those recommended, but not tested, by Mallet in the "Admiralty Manual"; but common pendulums, vessels filled with liquids, bodies floating in water, columns cylindrical and otherwise, and vertical springs were all, for one reason or another, found wanting. For several years (1872–85), the Tokyo earthquake record was made by a Palmieri seismograph. In the latter year this instrument was replaced by a Gray-Milne seismograph,

[1] *Trans.*, vol. 1, pt. 2, 1880, pp. 1–116; vol. 2, 1880, pp. 50–96; see also *Phil. Mag.*, vol. 43, 1897, pp. 33–6.

a combination of horizontal motion pendulums of the Ewing type and a Gray vertical motion seismograph, all recording in ink on a continuously moving strip of paper, so that the register could be continued without interruption except for the brief interval during which the paper was being changed.

In 1880 Gray had rediscovered the type of horizontal pendulum first devised by A. Gerard in 1851, the heavy mass being carried on a horizontal rod, the pointed end of which rests in a conical hole of the upright frame, while the mass is supported by a wire attached to a point of the frame nearly but not quite vertically above the pointed end of the rod. Realizing the value of such a pendulum for the registration of distant earthquakes, Milne, before he left Japan (1892), invented the instrument afterwards widely known as the Milne seismograph. With various modifications, it became for many years the standard instrument of the Seismological Committee of the British Association, and with it a vast amount of useful work was done. It is now being gradually replaced by the much-improved Milne-Shaw seismograph.

Nature of Earthquake-Motion.—One can well understand the interest of the early meetings of the Seismological Society when the first precise records of earthquake-motion were exhibited by Ewing and Milne. Most of the shocks in those days were comparatively slight, but they were strong enough to reveal the general character of the motion. Some of the results were unexpected, especially the small amplitude of the movement, which, in ordinary earthquakes is often less than one millimetre and seldom exceeds a few millimetres, while the maximum acceleration usually ranges from 10 to 100 mm. per second per second, and only in destructive earthquakes surpasses 500 mm. per second per second. The main conclusions are perhaps too well known to require rehearsal here. Some reference must, however, be made to the many seismic experiments which Milne conducted, for the most part in conjunction with Gray, and to Milne's study of the variations of the movement within a small area and under certain artificial conditions.

The registration of earthquakes, it might at first sight be expected, would give all the information desired. But the earthquakes came at uncertain times and from different regions. The observing stations were limited in number and required arrangement with reference to the source of disturbance. Above all, that source was usually of considerable size, and distortional vibrations from the nearer parts of the focus combined with condensational vibrations from more distant portions. It was necessary, therefore, to simplify the disturbance, and this was attained by explosions of dynamite and by dropping a heavy weight (1710 lb.) from various heights up to 35 feet.

The most interesting result of the experiments was the complete separation of the condensational and distortional vibrations. When the record was made with a single index on a fixed glass plate, the

index first moved in a straight line away from the origin. After this it was suddenly deflected and yielded a diagram in which the movement was elliptical or in the form of the figure 8, the two sets of vibrations being then compounded. When, however, two bracket seismographs of the Ewing type were installed, one to record the movement in the direction of the source, and the other in the perpendicular direction, the vibrations of the two types were kept apart, and the variations of each could be studied. Near the origin the amplitude of the condensational vibration was the greater, but died out more rapidly than that of the others with increasing distance from the origin. In both types of vibration the period increased as the waves diverged. In the velocity of the waves Milne found many variations. It increased, for instance, with the strength of the disturbance, and, in any one artificial earthquake, it diminished as the waves spread outwards. In the condensational vibrations the mean velocity was 438 feet per second; in the distortional vibrations, 357 feet per second. The effect of inequalities in the ground were also studied. Small hills seemed to interpose but little obstacle to the waves; excavations, such as ponds, checked the passage of both types of vibration.

A matter of some practical consequence brought out by these experiments is that two points of ground only a few feet apart did not always synchronize in their movements. This result led Milne to make some further observations during earthquakes, and he was able to show that points only 3 or 4 feet apart experienced slightly different motions. He also made a seismic survey of about 9 acres in the grounds of the Imperial College of Engineering at Tokyo. On the west side the ground is somewhat marshy; elsewhere it is dry and hard. He found that, as is now well known, the maximum acceleration (which measures the intensity of the shock) was greater on the soft than on the hard ground. An unexpected result was that the acceleration at the bottom of a pit 10 feet deep was much less than at the surface.[1]

Catalogues of Japanese Earthquakes.—During his residence abroad Milne compiled two catalogues of Japanese earthquakes, one showing the distribution of seismic activity in past time, the other the distribution throughout the country within a limited period. The earlier catalogue is less well known than it deserves. It contains a list of 366 great earthquakes, from 295 B.C. to A.D. 1872, and gives for each shock the date, the intensity (according to a rough scale of two degrees), and the district chiefly affected. One result obtained from this catalogue is worth noticing. The increase in the number of entries towards the present day, which is so characteristic a feature of all other catalogues extending over many centuries, is not observable here from the seventh century onwards. The probable explanation, according to Milne, is that Japan has remained through-

[1] *Trans.*, vol. 10, 1887, pp. 1–36; vol. 12, 1888, pp. 63–6, 67–75; vol. 13, 1890, pp. 41–89.

out in the same state of civilization, while other countries have emerged from a state of semi-barbarism.[1]

Soon after the foundation of the Seismological Society, Milne began the systematic study of the distribution of Japanese earthquakes. He adopted the plan of distributing bundles of postcards among the Government offices in all important towns within a hundred miles of Tokyo. Every week a postcard was to be returned to him with notes of any earthquakes observed. The results of two years (1881–3) were enough to show the efficiency of the method (387 earthquakes were recorded during this time in north Japan), and to reveal the principal laws of distribution. The "barricade of postcards" was then extended northwards as far as Sapporo, 450 miles from Tokyo, but the labour and expense were becoming too great to be borne by one man, and the Imperial Meteorological Department, with its 968 reporting stations, was induced to carry on the work. The materials for the eight years 1885–92 were afterwards placed in Milne's hands, and thus enabled him to prepare his great catalogue of 8,331 earthquakes recorded in Japan during these years.

The value of this catalogue and the immense labour involved in its preparation can only be appreciated by those who, like myself, have spent some time in analysing its contents. For convenience of printing, the catalogue is in two parts. Together they give, for every earthquake, the date, the extent of the area disturbed, and the lengths of its axes, the position of the epicentre, and, when submarine, its distance from the nearest coast.[2]

Distribution of Japanese Earthquakes.—It was characteristic of Milne that he left the discussion of his great catalogue for the most part to other workers. He was mainly interested himself in studying the distribution of the Japanese earthquakes in space. For this purpose he divided the map of the whole country into more than two thousand rectangles by north-south and east-west lines one-sixth of a degree of longitude and latitude apart. These rectangles are all numbered, and the position of the epicentre in the catalogue is indicated by the number of the rectangle in which it lies. On the map, the epicentres are represented by dots spread uniformly over each rectangle, and it is seen at once that these dots are grouped in fifteen districts with definite boundaries, except that, in two districts, the shocks were so numerous that the boundaries are represented as straight lines beyond the proper limits, as there would not otherwise have been room to insert the dots.[3]

[1] Milne's catalogue of great Japanese earthquakes has been superseded by "The Earthquake Investigation Committee Catalogue of Japanese Earthquakes", compiled under the superintendence of the late S. Sekiya (*Journ. Coll. Sci.*, Imp. Univ., Tokyo, vol. 11, 1899, pp. 315–88, with a discussion by F. Omori, pp. 389–437).

[2] *Trans.*, vol. 3, 1881, pp. 65–102; vol. 4, 1882, pp. 1–30; vol. 7, pt. 2, 1884, pp. 1–87; *Journ.*, vol. 4, 1895, pp. i–xxi, 1–367.

[3] Another method of representing the distribution of these earthquakes is illustrated in the *Geogr. Journ.*, vol. 10, 1897, pp. 530–35.

The map confirms in detail the laws of distribution which Milne had already deduced from the earthquakes of north Japan during the years 1881–3. Of those earthquakes 84 per cent originated near the sea-coast or beneath the ocean. He again notices that the majority of earthquakes originate along the east coast and that in many of them the epicentres are submarine. Drawing lines in an east and south-east direction from the highlands of Japan into the Pacific Ocean, he found that the slope in places is as much as one in thirty or twenty, and that it was in such districts where the surface-flexures are greatest that the earthquakes are most frequent and violent. A second and somewhat unexpected result is that the central portion of Japan, in which active volcanoes are numerous, is singularly free from earthquakes. Lastly, Milne showed that with two or three exceptions the districts in which earthquakes are frequent are also those in which movements of secular elevation and depression are taking place.[1]

Catalogue of Destructive Earthquakes.—The homogeneity of the second catalogue of Japanese earthquakes fails us in all catalogues extending over many centuries. Milne sought to restore this valuable feature to his last great work—the catalogue of destructive earthquakes—by confining it to shocks which have caused some marked injury to property, those due to " movements which have probably resulted in the creation or extension of a line of fault ". Even so, the catalogue is inevitably incomplete. For instance, during the first thousand years of the Christian era the records of three out of every four earthquakes come from Italy, China, and Japan ; during the nineteenth century the proportion drops to one in five. Many of our seismic records only began to exist during the last five centuries, that of America in 1520, of the Philippine Islands in 1600, of India in 1668, and of New Zealand in 1848. Nevertheless, unless some unexpected sources of information should be disclosed, it seems unlikely that very material additions can be made to Milne's catalogue. It must be regarded as exhaustive as it is now possible to render it.

The catalogue, which occupied Milne for several years, was published in 1911. It covers a period of 1893 years, from A.D. 7 to 1899, and contains 4,151 entries. As far as possible it states for every earthquake the year, month, and day of its occurrence ; the country visited by it, and often the part of the country in which it was felt most strongly ; the intensity of the shock according to a scale of three degrees ; and lastly the authorities for the information given. Sometimes a few details are added, such as the number of lives lost or of houses destroyed, which furnish a more precise idea of the disastrous character of the earthquake.[2]

Distribution of Earthquakes in Time.—Incomplete as the catalogue may be for the whole world, Milne points out that for Europe from

[1] *Journ.*, vol. 4, 1895, pp. xiv–xvii.
[2] *Rep. Brit. Assoc.*, 1911, pp. 649–740.

the year 1000 the most destructive of all earthquakes can hardly have escaped record. They were events of historical importance. Grouping them in periods of fifty years, from A.D. 1000 to 1850, he shows that, from about the year 1650 there has been a rapid increase in frequency, the numbers in successive half-centuries from 1600 being 3, 10, 15, 17, and 30. He suggests that these figures indicate a real increase in seismic activity from about 1650, accompanied, as he showed later, by a corresponding increase in volcanic activity.

The rest of Milne's work on the variations of earthquake-frequency must be noticed somewhat slightly, as, owing to the brevity of his record of world-shaking earthquakes, the results must be regarded as suggestive rather than as established. Like Mallet, he was attracted by the alternations of seismic activity and repose, and he showed that earthquakes have a tendency to occur in groups, the number in a group usually varying from two to fifteen or more, the groups lasting from one to three days, seldom more than six days. The interval between the centres of successive groups varies from fifteen to fifty days, being roughly proportional to the intensity of the earlier group.

More remarkable still is the tendency of strong earthquakes to occur in pairs, and even in triplets, in districts so widely separated as, for instance, Guatemala and the Indian Ocean (19th April, 1902), the interval between them being in this case less than the time required for the first preliminary tremors to cross the distance between the foci. Milne records fifteen cases of great double earthquakes, and two of triple earthquakes, during the years 1899–1906.

Such inquiries lead naturally to the suggestion that the variations of frequency in widely separated districts may to a certain extent be synchronous. The materials are perhaps at present insufficient for such wide generalizations, but Milne gives reasons for supposing that, in two districts so far apart as the eastern and western margins of the Pacific, the frequency in one increases and decreases simultaneously with that in the other; and that during the last two centuries, Italy, Japan, China, and America have roughly agreed in their periods of activity and repose.

The last point to which I can refer is Milne's interesting suggestion that the frequency of great earthquakes may be connected with the migrations of the pole. The earthquakes of the years 1892–1904 were grouped in successive intervals of 36½ days each. Counting the earthquakes in those intervals in which changes of direction took place in the movements of the pole, and in the preceding and following intervals, Milne found the numbers to be respectively 287, 167, and 217, and he thus concludes that great earthquakes are frequent about the times when changes occur in the direction of the polar movements, and especially when those changes occur most rapidly.[1]

[1] *Rep.*, 1900, pp. 107–108; 1903, pp. 78–80; 1906, pp. 97–9; 1908, pp. 78–9; 1909, pp. 56–8; 1910, pp. 54–5; 1911, pp. 32–5, 36–8; 1912, pp. 92–4.

The Study of Distant Earthquakes.—Milne's study of earthquakes extended over an interval of about thirty-three years. From 1880 to 1892, or during the existence of the Seismological Society, he was mainly concerned with ordinary earthquakes as they are felt within their disturbed areas. The next three years, while he was editing the *Seismological Journal*, formed a period of transition; his attention was divided between local and distant earthquakes; he was experimenting with the horizontal pendulum, afterwards known as the Milne seismograph. From 1895 until his death in 1913, or during his second residence in England, his time was chiefly devoted to the observation of distant earthquakes, with occasional digressions on the distribution of great earthquakes in space and time. In the present section I will touch briefly—for his work is so recent and well known—on his contributions to the latest and most fascinating development of seismology.

As far back as 1883, Milne had foreseen this development when he wrote that "it is not unlikely that every large earthquake might, with proper instrumental appliances, be recorded at any point on the land-surface of our globe". But it was not until 1889 that his attention was thoroughly aroused. In that year many Japanese and other earthquakes were recorded by von Rebeur-Paschwitz's horizontal pendulum at Potsdam, Wilhelmshaven, and elsewhere. Four years later Milne was observing distant earthquakes in Tokyo with his own seismograph, and his last report (1895) on the earthquake phenomena of Japan contains a list of some of the shocks recorded there before his observatory was destroyed. He reached Shide on 30th July, 1895, and within three weeks a brick pier was built, and the first horizontal pendulum erected in what afterwards became the central earthquake-observatory in the world.

In 1894 von Rebeur-Paschwitz suggested the foundation of an international system of earthquake-observatories, but his early death within the next twelve months cut short a promising career and delayed for several years the fulfilment of his plan. Shortly afterwards Milne independently conceived a similar and much wider network of stations, and in 1897 the Seismological Committee adopted his horizontal pendulum as the standard instrument for the purpose. Beginning with his observatory at Shide, the network of stations extended year by year, until the number of stations contributing records to the committee amounted to thirty-four. In the British possessions they were to be found in Canada and British Columbia, in Ascension and the Cape of Good Hope, and in various districts of India, Australia, and New Zealand. Records were also sent to the Committee from several observatories in foreign countries—from Spain, the Azores, and Syria, and from such distant island stations as Fernando Noronha and Honolulu.

The reports of the Seismological Committee, so far as Milne was responsible for them, are chiefly concerned with the discussion of the registers from these various stations. He touched, however,

on many subjects, some of which—such as earth-tremors, the diurnal wave, and the tilting due to tidal loading—have no apparent connexion with earthquakes. The sections on the distribution of earthquakes in time have been already noticed. Some others relating to distant earthquakes—such as earthquake-echoes, the nature of the large waves, and the dissipation of earthquake-motion as the waves radiate outwards—must here be passed over. In the remaining outline of Milne's work I will confine myself to two important subjects—the time-curves of the different phases and the distribution of the earthquake-origins in space.

It is interesting to trace Milne's successive attempts to draw the average time-curves of the earthquake-motion. The first, which is really a velocity-curve, appeared in the report for 1897, but the observations (for earthquakes of 1891–6) were discordant, and the only result deduced was an increase in the velocity of the early tremors with the distance, whether measured along the arc or the chord. In the following year an advance was made by separating the preliminary tremors and the large waves, and a curve was given showing very clearly that the average duration of the preliminary tremors increased with the arcual distance of the origin. In 1900—these years are dates in the history of seismology—the first time-curves proper were drawn. Distances from the epicentre in degrees of arc were measured along the horizontal axis, and the times of transit of the initial preliminary tremors and the maxima of the large waves to particular stations in the perpendicular direction. The time-curve for the large waves is practically a straight line, corresponding to a constant arcual velocity of 3 kms. per second; that for the preliminary tremors shows that the velocity along the arc increases with the distance. Two years later the curves begin to assume their now familiar form; and, as they are based on records from Milne's seismographs only, the divergences from the average are less noticeable than before. It had been shown by Oldham in 1900 that the preliminary tremors are divisible into two series, the first consisting mainly of condensational, the second of distortional, vibrations. A curve of the duration of the first preliminary tremors was also added. In the 1903 report the bearing of these curves is discussed. Measured along the arc from 20° to 150° from the origin, the velocity of the first tremors increases from 10·5 to 16·3 kms. per second. Measured along the chord the velocity is more nearly uniform, increasing from 10·5 to 12·0 kms. per second, and showing that there is apparently a slight increase in speed as the paths approach the centre of the earth. The interpretation which these observations require according to Milne is a "globe with an approximately uniform nucleus not less than $\frac{19}{20}$ of the earth's radius covered by a shell which passes rapidly upwards into the materials which constitute the crust of the world".[1]

[1] Since 1902, many hundreds of new observations have been collected, and these have naturally modified Milne's curves and the tables founded on them.

To locate the epicentre of a distant earthquake Milne employed chiefly two methods. The first depended on the constancy of the velocity of the maximum large waves and required the absolute times of their passage at not less than four stations. The second depended on the fact that the interval between the initial tremors and the maximum large waves is constant for the same distance from the epicentre and varies with the distance. Thus, if the interval were given for at least three stations, the corresponding distance could be determined from the time-curves and tables, and the intersection of the circles with centres at the stations and these distances as radii would give the position of the epicentre.

In the report for 1900 the first map of earthquake-origins (for 1899) was given, the positions of the epicentres being denoted by small circles. By 1902, the number of origins being increased, Milne found it possible to define the principal regions of seismic activity. From this time onwards the map was a feature of each year's report, retaining the same form until 1910, when greater detail could be attempted. The great merit of the maps is their completeness, for of the stronger shocks not one can now escape being recorded. On the other hand, the period that has elapsed since 1899 is but a brief interval in the history of the earth, and all that the maps can provide us with is an outline of those districts in which crustal changes are at the present time taking place most rapidly. From the map for 1899–1909 we see that of every ten earthquakes seven belong to the districts bordering the Pacific Ocean, one to the strictly oceanic districts of the Indian and Atlantic Oceans, and two to the great terrestrial district which extends from the Apennines to the east of the Himalayas.

Conclusion.—In the preceding summary of Milne's work in seismology, I have omitted many points of interest. As somewhat outside our range I have left untouched the practical applications to which he humanely devoted so much of his time and attention, and especially to the structure of earthquake-proof buildings.[1] In common with other seismologists, Milne became absorbed for a time (especially 1884–6) in the study of earth-tremors. The early results obtained with his "automatic tremor recorder" were to some extent corrected by his later observations with the horizontal pendulum. Moreover, the connexion between earthquakes and tremors seems to be somewhat remote.[2] In 1897 he read an

The latest and most trustworthy tables are those prepared by Turner and published in the Circulars issued by the Seismological Committee. The bearing of the time-curves and especially that of the second preliminary tremors, on the constitution of the earth, has been discussed by several writers, especially R. D. Oldham (*Quart. Journ. Geol. Soc.*, vol. 62, 1906, pp. 456–73) and C. G. Knott (*Proc. Roy. Soc. Edin.*, vol. 39, 1919, pp. 157–208).

[1] *Trans.*, vol. 1, pt. 2, 1880, pp. 64–85; vol. 2, 1880, pp. 27–38; vol. 11, 1887, pp. 115–74; vol. 14, 1889, pp. 1–246; vol. 15, 1890, pp. 163–9.

[2] *Trans.*, vol. 7, pt. 1, 1883–4, pp. 1–15; vol. 11, 1887, pp. 1–78; vol. 13, 1890, pp. 7–20; *Rep.*, 1895, pp. 27–31.

interesting paper before the Royal Geographical Society on sub-oceanic changes as revealed by the fracture of telegraph-cables.[1] There were, indeed, few branches of seismology to which at one time or another Milne did not attend. On only one important subject did he touch less than might have been expected, namely, the origin of earthquakes, but the references which he made to it here and there show that he held the modern view which attributes earthquakes to the formation and growth of faults.

To state, as I have done for Michell and Mallet, what seem to me to be the contributions of permanent value which Milne made to seismology would be merely to abbreviate and repeat the preceding pages. I will therefore confine these concluding remarks to two general features.

In a history of seismology, Milne's work must for all time occupy a large and worthy place. In our textbooks of the future, in books which aim at presenting a summary of the then existing knowledge, the references may be fewer as time goes on than his work deserves. It must be remembered that Milne was a student of earthquake-phenomena, and that our knowledge of the phenomena is always growing. A careful investigation of a great earthquake, on the other hand, retains its value, for it cannot be replaced. Moreover, he preferred sometimes to start an inquiry and to leave others to finish it, to open up large views and to provide promising subjects of inquiry for a future of wider knowledge. Of his two great catalogues—of Japanese earthquakes and destructive earthquakes—his own analysis was slight. He was, in fact, content to provide the materials which others were to use in building.

The influence of a leader in science extends far beyond his own contributions. In founding the Seismological Society of Japan, which led to the formation of the Imperial Earthquake Investigation Committee, and in organizing the network of stations throughout the world, and, above all, in his personal influence on those with whom he came in touch, it seems to me possible that seismology may owe almost as much to his guidance and inspiration as it does to the incessant labour of his well-spent life.

[1] *Geogr. Journ.*, vol. 10, 1897, pp. 129–46, 259–85.

ORIGINAL ARTICLES.

The Use of Graphs in Palaeontology

By H. H. Swinnerton, D.Sc., F.G.S., F.Z.S., Professor of Geology, University College, Nottingham.

(*Concluded from p. 364.*)

Examples from Carboniferous Corals.

To illustrate the value of graphic methods when changes in a number of distinct structural elements are studied, examples may be taken from the Carboniferous corals. These are well suited to the purpose, because thin slices yield so much information and are easily measured. In Fig. 4 a diagrammatic section is shown of one of the most highly organized corals, which exhibits the following important structural units: epitheca, tabulæ, septa, dissepiments, tabellæ, lamellæ, columella.

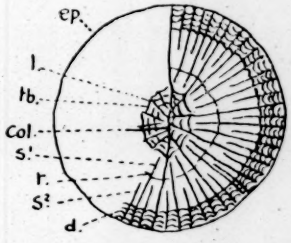


Fig. 4.—Diagrammatic section of *Dibunophyllum* showing the structural elements with which it is constructed. *ep.* epitheca, *l.* lamella, *tb.* tabella, *col.* columella, s^1. major septum, *t.* tabula, s^2. minor septum, *d.* dissepiment.

As shown by the accompanying table (Table I), the mere presence, or absence, of one or more of these units constitutes an important diagnostic feature for many genera. This table shows that these

	Tabulae.	Septa.	Dissepiments.	Tabellae.	Lamellae.	Columella.
Favosites.	×	–	–	–	–	–
Zaphrentis.	×	×	–	–	–	–
Caninia.	×	×	×	–	–	–
Cyathophyllum.	×	×	×	×	–	–
Aulophyllum.	×	×	×	×	×	–
Dibunophyllum.	×	×	×	×	×	×
Lithostrotion.	×	×	×	–	–	×
Cystiphyllum.	×	–	×	–	–	–
Duncanella.	–	×	–	–	–	–

Table I.—This illustrates the combinations of structural elements present in various corals. × element present, — element absent.

units are not so immutably correlated with one another that the presence of one of necessity involves the presence of all the others; thus the presence of the columella does not involve the presence of the tabellæ, nor the dissepiments that of the septa. Had these units all been immutably correlated, then only one morphological series of corals would have been possible, and Carboniferous palæontology could then have been studied without tears. In actual fact the elements may be present or absent in varying combinations, and thus a wide variety of coral types may exist. The number possible is a matter for mathematical calculation. The real number may be smaller, for a coral consisting, for example, of tabulæ alone is inconceivable.

The Measurement of Structural Units in Corals.

Not only do the structural units vary as to their presence or absence, but the individual elements themselves are also subject to perpetual change in quite definite directions.

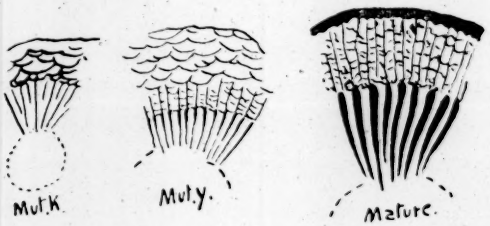


Fig. 5.—Portions of sections of mutations K, γ, δ from the gens *Caninia cylindrica* (after Vaughan).

A brief inspection of a number of coral-slices of several genera, or of different parts of the same individual, will show that the elements differ in the various slices. These differences may be sorted out and arranged in series. Thus the inner ends of the major septa (Fig. 5) may be withdrawn from or approximated towards the centre. Similarly the outer ends may extend to or be separated from the theca (Fig. 5). This incidentally furnishes an illustration of the same unit being affected by two divergent series of changes. In both cases the changes may be accurately recorded by measuring the distances of the inner and the outer ends of the septa from the epitheca. The figures may then be expressed as percentages of the average diameter of the coral.

Where minor septa have become units of sufficient prominence they, too, may be measured in the same way. For both kinds of septa the total number present is a feature of some importance.

The dissepiments occupy a wide or narrow zone which always lies in contact with the epitheca. The width of this zone is easily measured, and, again, may be expressed as a percentage of the coral diameter.

Many lamellæ are in reality the central continuation of the septa, from which they often become separated at the edge of the tabellar zone. New lamellæ, having no relationship to the septa, often arise between the old ones. The total number may be counted and recorded.

Not uncommonly the lamellæ and the central ends of the septa become curved in various degrees, and may even become strongly spiral or even crumpled. These differences, which may form one or more series of changes, do not admit of easy measurement. In such cases the method of procedure is to represent the main steps in the series from one extreme to the other by five or ten diagrams. The extremes are then taken to be 0 and 100 respectively, and thus the stages in the development of curvature, represented by the diagrams, can be expressed as percentages of the maximum curvature.

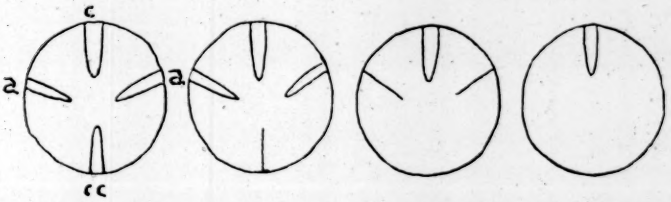


FIG. 6.—Diagrams representing some of the stages in the serial reduction of the fossulæ in Carboniferous corals. *c*. cardinal fossula, *cc*. counter-cardinal fossula, *a*. alar fossulæ.

This method of using a series of diagrams may be applied to differences exhibited by the columella. In some corals this unit is merely the central portion of a median partition, which stretches across the coral (Fig. 4 col.). In others this septum is broken on the cardinal side of the centre. In others, again, it is broken on the counter-cardinal side also. The columella also exhibits various degrees of thickening. The history of the columella, however, is not simple, and requires more discussion than the scope of this paper will allow.

The passage from bilateral to radial symmetry is an important direction of change which undoubtedly takes place in numerous quite separate lines of descent, and expresses itself with the help of several structural units, such as the major and minor septa and the fossulæ or depressions in the tabulæ.

The changes, in so far as they involve the fossulæ, range from the presence of four fossulæ (Fig. 6) in bilaterally symmetrical corals, through various stages in the reduction first of the counter-cardinal, and then of the alar, and finally of the cardinal fossulæ, to the complete absence of all four in the radially symmetrical corals. Along some lines the alar fossulæ go before the counter-cardinal one does. In either case diagrams, representing stages at different percentage intervals from one extreme to the other, may be drawn.

Of the major septa only four or six approximate to a radial

arrangement in a coral showing maximum bilateral symmetry (Fig. 7, *cs*, *ccs*, *a*). As the symmetry changes the percentage number of radial septa increases until all are radial. Even when major septa indicate only lingering traces of bilateral symmetry, the minor septa may still reveal it to a marked degree. These latter elements put in their first appearance on the counter-cardinal side of the section, and as their number increases they extend round to the cardinal side, until there are as many minor as there are major septa. The number of minor septa expressed as a percentage of the total number of major septa thus becomes another measure of the serial change from bilateral to radial symmetry.

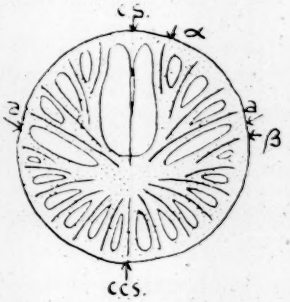


FIG. 7.—Section of *Zaphrentis delanouei* (after Carruthers, *Q.J.G.S.*, 1910, pl. xxxvii, fig. 3A). *c.s.* cardinal septum, *c.c.s.* counter-cardinal septum, *α* the shortest septum in one of the cardinal quadrants, *β* the shortest septum in one of the counter-cardinal quadrants.

The following examples will serve to illustrate the way in which these numbers and percentages may be expressed graphically, and so be used for the solution of evolutionary problems. The measurements used here have all been made upon the published figure of easily accessible and important pieces of work. The examples chosen are useful as tests for, as well as illustrations of, the method. The first is from a paper containing a careful and detailed description of the development of one coral. The second is from another, by the same author, in which the evolution of a species is traced in a manner closely approaching the ideal, and results are attained which cannot be refuted. The third is a fair example of the practice of linking together in series, mutations which, in the opinion of a specialist, "are continuously related either in space or time." [1]

EXAMPLE II: THE DEVELOPMENT OF CANINIA CORNUCOPIÆ.

On plate vi of Carruthers' paper [2] on the development of *Caninia cornucopiæ*, figs. 1*b* to 1*j* represent slices cut across the coral at different levels from the apex to the calyx. They, therefore, record the changes which are passed through in development. Many

[1] Vaughan, *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, p. 183.
[2] Carruthers, GEOL. MAG., 1908, p. 158.

different measurements may be made, but only those which reflect distinct changes have been taken into account here. They are the following :—

(A) The percentage number of septa that have become distinctly radial in their arrangement. In addition to lying along a radius, this implies that they are equal in length.

(B) The number of minor septa expressed as a percentage of the total number of major septa.

(C) The reduction of the fossulæ.

(D) The percentage number of septa in the counter cardinal quadrants.

(E) The number of septa as a percentage of the total number in the adult.

(F) The diameter of the central space occupied by the septa.

(A) to (D) relate chiefly to changing symmetry.

(F) reflects both the progressive extension of the central area, which becomes occupied by tabulæ alone, and a gradual shortening of the septa themselves.

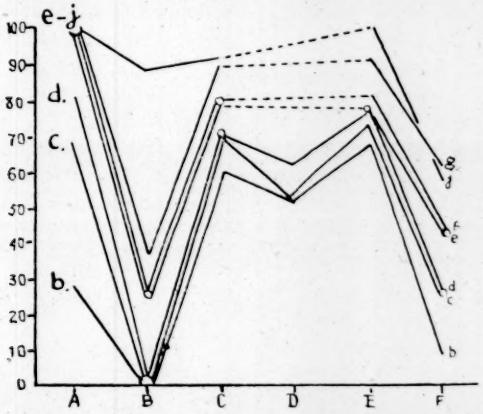


FIG. 8.—A series of graphs representing stages in the development of *Caninia cornucopiæ*.

In Fig. 8 the line *b* represents the measurements on Mr. Carruthers' fig. 1*b*. This was the earliest stage in development described by him. The other lines correspond to his figs. 1*c* to 1*j* respectively.

It is at once evident that the graphs, though they are not parallel, develop out of one another in sequence ; that is to say, that with one slight exception they do not cross one another. The slight exception is the crossing of *g* and *j* between E and F. In the absence of later stages than *j* it is impossible to explain this. It may be due either to a reversal of the direction of development, or to that fluctuation about a mean which characterizes an element that has

become stationary. In the absence of further evidence this may be neglected.

As already seen in Example I, taken from Palæozoic echinoids, the rate of change of any one element is not necessarily the same as that of any other element. Had the rates of change been equal the lines would have been parallel. Comparing A and B, it will be seen that while A changes rapidly from *b* to *d*, B is stationary. When A has reached its maximum development and has become stationary, B progresses by leaps and bounds. The facts almost suggest a principle which may be described as the conservation of developmental energy. It is as though the energy were limited, so that when it is being used freely on one element, another must develop slowly or become stationary.

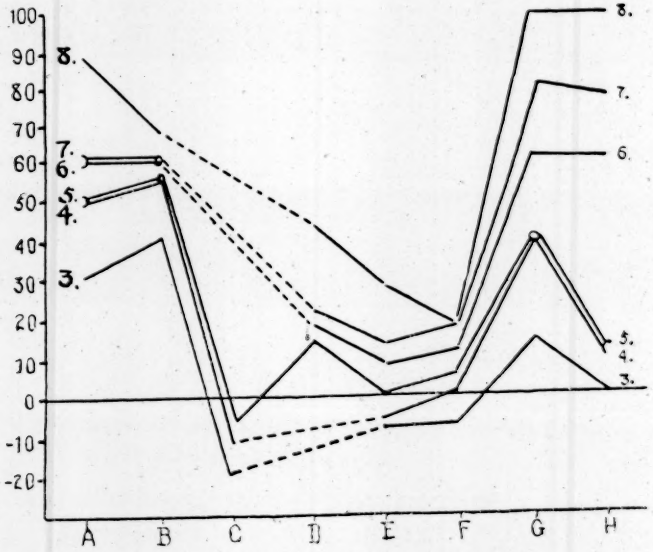


FIG. 9.—Series of graphs representing the stages in the evolution of *Zaphrentis delanouei*.

EXAMPLE III: THE EVOLUTION OF ZAPHRENTIS DELANOUEI.[1]

As already indicated, this is one of those rare cases in which the palæontologist's dream of a perfectly worked out lineage is as near fulfilment as is humanly possible. That the series *delanouei*, *parallela*, *constricta*, and *disjuncta*, is a genetic series cannot be denied. The evidence adduced from the study of development, distribution, variation, and succession in the rocks is overwhelming. The measurements represented graphically in Fig. 9 were made upon the following figures on pl. xxxvii of Mr. Carruthers' paper :—

[1] Carruthers, *Quart. Journ. Geol. Soc.*, vol. lxvi, 1910, p. 523.

3*a*.	*Zaphrentis delanouei.*		6*a*.	*Zaphrentis disjuncta*	(early).
4*a*.	„	*parellela.*	7*a*.	„	„ (typical).
5*a*.	„	*constricta.*	8*a*.	„	„ (advanced).

The changes measured were as follows :—

A. The reduction of the fossulæ.

B. The length of the cardinal fossulæ from the epitheca to central stereom, or when this has disappeared, to the inner end of the counter cardinal septum. This is expressed as a percentage of the diameter.

C. The width of the fossula at its inner end, expressed as a percentage of the diameter.

D. The distance between the inner ends of the alar septa, expressed as a percentage of the diameter. This reflects the progressive shortening of the septa and their withdrawal from the centre.

E. The percentage length of the shortest septum in the cardinal quadrants (cf. Fig. 7*a*).

F. The percentage length of the shortest septa in the counter-cardinal quadrants (Fig. 7β).

G. The reduction of the central stereom.

H. The percentage of free septa.

Measurements E to H call for further explanation.

Taking E and F first, at stage 3 (Fig. 9), the septa still exhibit a markedly pinnate arrangement. During the succeeding stages the shortest septum in each quadrant, viz. those which lie next to the cardinal and alar septa on the counter-cardinal side (Figs. 7*a*, β) undergo striking changes which reflect two important alterations affecting the coral as a whole.

The first or earlier alteration is the passage from a pinnate to a radial symmetry. Whilst this is taking place the short septa elongate until they are equal in length with the other septa.

The second and later alteration takes place when an advanced stage in the attainment of a radial symmetry has been reached. All the septa now begin to shorten and to withdraw simultaneously from the centre. This change is also shared by the four septa under consideration.

These four septa thus elongate during the earlier stages and shorten during the later stages of evolution. This reversal in the direction of change of these septa is most simply expressed in graphic form by placing the point of reversal on the zero line, and representing the changes which precede it below and those which follow above the line.

Turning now to G and H, in stage 3 (Fig. 9), there is a considerable deposit of stereom at the centre of the coral, which binds the inner ends of the septa together. With the progress of evolution the stereom becomes reduced in quantity and the septa gradually become liberated. This change can be expressed either in the form of a series of diagrams representing the reduction of the area of the stereom (G), or by figures giving the percentage of free septa (H).

If now the graphs of these measurements be examined (Fig. 9), it will be seen that the lines 3 to 8 follow one another in sequence and without crossing, so that the same conditions hold good for a phylogenetic as for an ontogenetic set of graphs. Again, the rate of change in one structural unit is not necessarily the same as for another, and thus the conception of the independence of the various serial changes receives further confirmation.

It is interesting to observe that in 4 and 5, in which a reversal of direction of change takes place in some elements, the other elements come temporarily to a standstill. Again, in 6 and 7, whilst G and H progress rapidly, A and B remain stationary. These facts seem to indicate the existence of a principle of the conservation of evolutionary energy.

Example IV : The Gens Caninia cylindrica.[1]

Another method of establishing lineages is resorted to when the material to hand is limited. It is based upon the quite reasonable assumption that a specialist on any group of fossils is thoroughly familiar with the various combinations of resemblances and differences of a wide range of types. This familiarity enables him to detect those forms which are so closely allied to one another that they must evidently belong to one genetic series, gens or lineage. Once he has established a reputation for reliability his conclusions are naturally accepted by his fellow-workers, until such a time as another specialist upon the same group arises to either refute or confirm his findings. The method of graphic representation explained above supplies an alternative means of testing the genetic affinity of apparently similar forms when the material is not abundant, and the investigator is not a specialist.

In the late Dr. Vaughan's paper on the Dinantian and Avonian he publishes a series of sections (pl. iii, figs. 1–5) across five corals, which he calls mutations *K*, *β*, *Z*, *γ*, *ĉ* (cf. fig. 5 above), and which he regards as a gens or a series of " continuously related " forms.

After making many different measurements of the elements in each of his five figures the following series of changes were found to be important and instructive :—

(A) The number of minor septa.
(B) The number of major septa.
(C) The length of the major septa.
(D) The distance of the outer ends of the septa from the epitheca.
(E) The width of the dissepimental zone.

These measurements are reproduced in graphic form in Fig. 10. From this it will be seen that the graphs *K*, *β*, *ĉ*, fulfil all the requirements of a genetic series ; that *Z* transgresses slightly across the other graphs, and presumably is not distantly removed from the

[1] Vaughan, *Quart. Journ. Geol. Soc.*, vol. lxxi, 1915, p. 36

series; but that γ is very much out of accord with all the others, and therefore lies quite distinctly off the true line of descent.

General Remarks.

In laying emphasis upon the principal of the independence of flow-lines of change in structural elements it is not intended to deny the principle of the correlation of parts. On the contrary, it is held that the wonderful correlation of parts, which characterizes all organisms which survive the vicissitudes of ever-changing surroundings, is the outcome of a continual adjustment of the parts to one another. Such an adjustment can be attained only if the parts are free to change this way or that with independent velocities. Only by such independence, for example, could the five-toed primitive mammals have given rise to such diverse types of feet as those of the horse, the elephant, and the sloth.

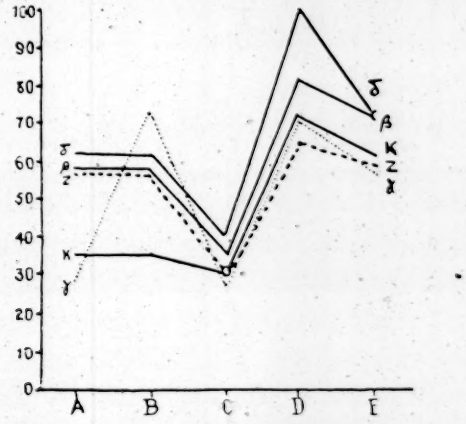


Fig. 10.—Series of graphs representing the mutations of the gens *Caninia cylindrica*.

Whilst a description of these three types of feet may be quite diagnostic of these three mammals, it is not diagnostic of the genetic series to which each belongs, for such a series exhibits continual change as it is followed through time. In this case, it is the direction and velocity of change in homologous parts which is diagnostic.

In palæontology the time factor is of supreme importance. On this account it is not the species, but the flow-lines of change, with or without clearly defined structural units, which provide the easiest points of attack for the study of evolutionary problems. Indeed, the separation, and the elucidation of the behaviour of these flow-lines, which clustered together constitute the lineages of various groups, is a necessary preliminary to the unravelling of phylogenies and the solving of problems in heredity.

As already shown, homologous units in separate genetic series

are frequently the subjects of the same limited range of changes. Owing to the varying rates of change of the elements in different lines of descent, the majority of varieties and species as a whole are quite distinguishable from one another. If, however, several elements happen to attain the same stages together in two or more of these lines a resemblance, often quite striking, arises between even distantly related organisms. This phenomenon finds expression in the terms " morphological equivalence ", " homœomorphy ", " convergence ". If these same structures maintain the same relative rates of change, that is to say, if they become correlated with one another, then a series of homœomorphs will result. In any case the goals towards which the flow-lines of changes tend may be the same in quite divergent lines of descent. In the later history of several such lines it often happens that first one and then another homologous structural element reaches its goal, and morphological resemblance becomes dominant. The only escape from this blind alley of homœomorphy and convergence is either by extinction or by reversal of the direction of change.

Some of the phenomena dealt with above bring the palæontologist within hailing distance of the Mendelian experimenter; for both are approaching the same problem from different angles. It may not be out of place therefore to express some of the thoughts which a comparison of the results attained by both classes of workers suggests.

The accompanying table gives a summary of Mr. Carruthers' discoveries concerning the distribution of the mutational stages in the evolution of *Zaphrentis delanouei* in time and space. In considering the figures it must be borne in mind that the distinction between stages or mutations (Waagen non De Vries.) is arbitrary, and corresponds to no breaks in the series.

Stratigraphical level.	*Z. delanouei.*	*Z. parallela.*	*Z. constricta.*	*Z. disjuncta.*
Millstone Grit .	—	—	5	95
Upper Limestone	—	·3	16	83
Lower Limestone	·7	·3	69	28
Cementstone group . . .	69	30	1	—

TABLE II.—This shows the percentage number of representatives of each stage at each of the four main stratigraphical levels.

From this it is evident that all the stages had representatives at the lower limestone level. Similarly at other levels several stages were present. Evidently, therefore, varieties which are contemporaneous with one another, may give a true representation of the evolutionary stages; and the differences between homologous structural units, shown in them, may mark out the lines along which changes in the units flow.

The biologist draws the varieties upon which he experiments

from one stratigraphical level, namely the present. The relationship of his material to that of the palæontologist is evident from what has just been stated. It is like a cross-section of lineages which stretch back into the, to him, inaccessible past.

Mendelian experiments of necessity deal only with (differentiating) characters belonging to homologous parts, e.g. the end of a pod, pointed or rounded; the edge of a leaf, much or little serrated; the epidermis of a plant, smooth or hairy. They deal, therefore, not with separate structural units as such, but with certain stages in the changes which they undergo. Thus, the end of a pod is not only either pointed or rounded, every gradation between these two extremes may be found, provided all pods are taken into account. The fact that such gradations do occur to-day indicate that pointedness and roundness have not arisen suddenly but gradually during past ages. So, likewise, with the edge of the leaf, the epidermis of a plant, and many other homologous parts which have supplied material for experimentation.

Where such gradation exists, the experiments appear to deal with the extremes of the series which correspond with such percentages, as, say, 0 and 95 or 10 and 70 of the scheme explained in the earlier part of this paper. If this be the case, some, at least, of the Mendelian unit characters are merely stages in the serial changes of a structural unit.

The fact that structural unit A at stage 0 or 10, for example, can be removed and replaced by the same structural unit at stage 95 or 70 without producing any corresponding change in the elements B, C, D, etc., furnishes yet further confirmation of the view that serial changes in one element are independent of those in another.

The terms structural unit and element used so frequently above seem at first sight to be synonymous with Osborn's unit character or biocharacter.[1] In so far as he defines this as a separable unit in ontogeny and phylogeny, the two are the same. But in his definition he appears to regard the biocharacter as being the same as a Mendelian unit character. Now the unit in ontogeny and phylogeny is something which changes continuously. The Mendelian character, on the contrary, is something which is quite fixed, and, within the limits of experimentation, unchangeable. If it were not so the experimenter would lose his bearings in the multiplicity of his filial generations. The view adopted here therefore is that the Mendelian unit character is not merely a structural unit, but a structural unit at a certain stage of evolution. The experimenter does not exchange one structural unit for another, e.g. horns for ears, but a structural unit at one stage of evolution for a homologous unit at another stage, e.g. long staple and short staple in cotton, presence or absence of horns in cattle.

Once more, it may be allowable to emphasize the fact that it is

[1] H. F. Osborn, *American Naturalist*, 1917, p. 449.

not always possible to state what are the precise anatomical or histological constituents which make up the "structural unit" under consideration. A term seems to be needed which will stand for the phenomenon referred to in this paper under such phrases as a "unit series of changes", "flow-line of change", "direction of change". Even a clearly defined structural unit may be the subject of several different but definite directions of change in less closely related lineages, cf. the ambulacral areas of palæozoic and modern echinoids, or the feet of perissodactyles and artiodactyles.

Tallness and dwarfness in peas have become classical subjects for experimentation. These two features in peas seem to belong to the same order of phenomena as narrowness and broadness of skull in Titanotheres. These types of skull have been proved to arise gradually from skulls of median proportions.[1] Judging by the fact that peas of all statures between tall and short exist to-day it seems not improbable that the tall and short races must likewise have arisen gradually, during the passage of time, from a race of median stature. Be this as it may, the tall and short peas, with which the experiments were performed, are to-day distinct races; that is to say, they belong to different lineages which breed true and which for a period of time have been pursuing divergent lines of evolution in respect of stature. The experimenter crosses the races and transposes the tallness of one line to the other line, and by so doing produces a new race having the usual characters of the dwarf pea except as regards stature. The fact that he is able to do this suggests that a similar exchange, likewise resulting in the sudden appearance of a new race, could and did take place in nature, for during the early history of allied lineages it is reasonable to infer that they would be as mutually fertile as these two races of peas. Thus, in Fig. 10 it is conceivable that mutation γ was produced by a cross between a form similar to K and one in which there were few minor and many major septa. If that has been the case then γ, like the experimenter's new race of peas, had a dual ancestry. This is, of course, purely hypothetical, nevertheless, it illustrates one type of problem that the use of graphic methods in palæontology may hope to solve. Meanwhile, the results of Mendelian experimentation produce the uncomfortable feeling that a palæontologist tracing lineages of species, or even in some cases, of genera to common ancestors is pursuing a "will-o'-th'-wisp", that converging lines of descent run back, not into a point, but into a network of incipient lineages, in which structural elements as they change are shuffled across, like strands, from one thread to another, until several combinations of developmental stages have been hit upon which are both stable and mutually sterile.

My thanks are due to my colleagues, Mr. H. S. Holden and Mr. A. W. Richardson, for much free discussion of the subject matter of this paper and for many helpful criticisms and suggestions.

[1] Osborn, *Bull. Amer. Mus. Nat. Hist.*, 1902, pp. 77–89.

An Outline of Chinese Geology

By J. S. Lee, M.Sc., Birmingham.

(*Concluded from p. 377.*)

The apparent conflict in palæontological evidence is still more aggravated if the views of several able palæobotanists be taken into consideration. Plant-remains have been frequently found from the Shansian rocks in various parts of northern China. They amount to a copious flora. Numerous species are described by Newberry, Schenk, Abbado, Zeiller, Zalesky, and Yokoyama.[1] In some cases these writers agree in assigning the flora to the Upper Carboniferous. The presence of *Tæniopteris multinervis*, which is said to have never been found in Europe below the Autunian stage, and a number of its allied species, such as *Lepidodendron gaudryi*, *Calamites* cf. *leioderma*, has, however, led Zeiller to conclude that the coal-bearing Shansian rocks in the Shan-si Province range from the highest Stephanian to the Lower Permian. Schenk also holds that the coal-bearing series of Kai-ping, eastern Chi-li, and that of Pen-hsi-hu, Manchuria, are of Permian age.

It is to be noted that the plant-remains occur in the strata closely associated with the coal seams; the coal seams usually occur above the limestone yielding the marine fossils, and are sometimes intercalated in it, but rarely found below it. When the coal seams occur above the limestone, the intervening rocks generally consist of sandstones and shales having a total thickness of less than 250 feet. It is therefore evident that even if we take the maximum thickness of rocks between the faunal and floral zones it can hardly be considered as sufficiently thick for representing such a long period of time as it would necessarily do if the fauna really belongs to the Lower Carboniferous. Suggestions have been made as to the possible existence of a stratigraphical break between the marine formation and the Productive Measures in the coal-fields of Shan-si and Shantung, but no known structural facts seem to support this idea. For future stratigraphical research the numerous species of Fusulinidea that occur in the marine limestone may yet prove to be of immense value as age-indicators. At present the presence of these Foraminifera, together with the flora, seems to justify the statement that the Shansian System represents a period not earlier than the Middle Carboniferous nor later than the youngest Permian.

With respect to the marine facies, it is best, under the light of our present knowledge, to take the development in eastern Yun-nan as a typical one. There the Anthracolithic Formation may be described as consisting of the following three series[2]:—

[1] *Smithsonian Contribution*, vol. xv, art. 4, pp. 121–3; *China*, vol. iv, pp. 211–44; *Palæont.*, vol. xxxi, 1885, pp. 163–82; *Palæont. italica*, vol. v, 1900, pp. 125–44; *Ann. d. Min.*, vol. xix, sér. ix, 1901, pp. 431–53; *Verh. K. Russ. M. Gesell.*, ser. ii, vol. xlii, pp. 385–98; *Journ. Coll. Sci. Imp. Univ. Tokyo*, No. 8, 1908, pp. 1–18.

[2] Deprat, op. cit., pp. 98–174.

c. Upper or Volcanic Series. Bedded andesite, basaltic lava, tuff, and other volcanic rocks followed downwards by a massive conglomerate and sandstone aggregating to a thickness of more than 1,800 feet; unconformably overlain by the Trias.

Unconformity

b. Middle or Fusulinidea Limestone Series. Light- and dark-grey limestones, locally sandy; total thickness about 3,800 feet; crowded with Fusulinidea. Faunistically this series can be subdivided into three parts: in the upper part the species *Doliolina lepida* abounds, *Neoschwagerina multiseptata*, *N.* (*Sumatrina*) *annæ*, *Fusulina exilis*, *Schwagerina verbeeki* are also of frequent occurrence; in the middle part a Lower Permian fauna of Brachiopods predominates over the Fusulinidea, *Spirifer blassi*, *Spirigerella grandis*, *Camarophoria globulina*, *Hemiptychinax sparsiplicata*, *Martiniopsis inflata*, *Productus gratiosus* being the more characteristic species; in the lower part *Neoschwagerina craticulifera*, *Schwagerina princeps*, *Fusulina multisepta*, *F. brevicula*, *F. regularis*, etc., occur in association with a number of species of Brachipoods belonging to the Upper Carboniferous, e.g. *Productus* cf. *subcostatus*, *P.* cf. *compressus*, *Reticularia lineata*.

Unconformity

a. Lower Series. Limestones followed downwards by coal-bearing sandstones, again limestone and then shales and sandstones; yielding *Spirifer mosquensis*, *Spiriferina cristata*, *Athyris* cf. *subtilita*, *Productus glabra*, *P. cora*, *P. striata*, *P. undatus*, *Productella spinulosa*, *Chonetes papilionacea*, *Orthothetes crenistria*, and many species of Gastropods and Lamellibranchs indicative of Muscovian and Dinantian or Middle and Lower Carboniferous age.

These series are traceable to a large extent outside the area of eastern Yun-nan. The Lower Series, with a fauna of Brachiopods, Lamellibranchs, and Gastropods, extends northward along the south-eastern border of the Great Red Basin of Su-chuan, passing the districts of Lan-mou-tchang, Wei-ning, in the province of Kwei-chou; the coal-fields of Nan-chuan, south-eastern Su-chuan [1]; and reaching the Shao-yang district [2] in central Hu-nan. *Orthothetes crenistria* appears to be one of the widely distributed species in the Lower Series. It is a remarkable fact that even in the limestones of this series none of the Fusulinidea which are so abundant in the Middle Series has yet been found.

The Middle Series, with its characteristic faunas of Fusulinidea and Brachiopods closely related to the fauna of the Middle Productus Limestone of the Salt Range, has been observed in the neighbourhood of Ta-li, Yung-tshang, Tze-de, Ngan-tshang-po, western Yun-nan; Ho-chang, Tung-tze, Sung-kan, north-western Kwei-chou; the Yakarlo district on the Tibetan border.[3] The limestone that forms a long range running from the north of Ta-li to the west of Ta-tsien-lu as observed by Loczy; the "Doliolina Formation" [4] that occurs in western Kan-su and the Semenow Mountain, south of the Kuku-nor;

[1] *China*, vol. v, pp. 77, 81–6.

[2] *Journ. Geol. Soc. Tokyo*, No. 263, p. 84, 1915; *idem*, No. 265, p. 139.

[3] Leclère, op. cit., pp. 30–1; Loczy, op. cit., pp. 188, 202; *China*, vol. v, pp. 167–75.

[4] *Durch Asien*, vol. ii, pt. ii, pp. 38, 116, 204–5.

and the *Fusulina*-bearing limestone in the Nan-shan Ranges undoubtedly represent at least a part of the Middle Series.

The Upper Series, though apparently less extensive, is nevertheless known in the Tang-tang district, on the northern border of Yun-nan, where it is underlain by the "Permo-Carboniferous Limestone" (= the Middle Series) and overlain by the Trias.[1] The pyroclastic rocks of the Sang-hu-shan,[2] south-eastern Hu-peh, that overlies the Permian coal-bearing series, is in all probability a representative of the Upper Series in the middle Yang-tze Valley.

The post-Middle Carboniferous and pre-Uralian unconformity deserves special notice. It is by no means a phenomenon limited to eastern Yun-nan. The important rôle that it plays in determining the structure of western China may be realized if we examine Obrutchov's report from the Nan-shan and Loczy's report from the mountains of western Su-chuan and western Yun-nan.[3]

In central China the unconformity, however, does not appear to exist. Willis and Blackwelder, in the course of their reconnaissance in western Hu-peh, distinguished a dark bituminous limestone, the Wu-shan Limestone,[4] representing, as may be inferred from the fossils so far obtained, the period ranging from the Lower Carboniferous to at least the Lower Permian. Further west similar limestones [5] have been found by Richthofen to the south of the Ning-kiang, and by Obrutchov in the valley of the Pei-sui-kiang.

The region of the lower Yang-tze Valley (below Kiu-kiang) affords good examples for showing the mixed development of the two facies of the Anthracolithic Formation. In this region we have the continental deposit of the northern type with coal seams as well as the massive Fusulinidea limestone of the south-west. From the record of Richthofen's observations and the *Record of the Work of the Geological Institute* it appears that the Carboniferous-Permian rocks in the lower Yang-tze Valley can be generally divided into three series in the following order :—

c. Upper or Coal-bearing Series. Sandstone and coal-bearing shale with intercalated marine limestone, yielding a fauna related to that of the Middle Productus Limestone of the Salt Range and of Sumatra. The more characteristic species are *Reticularia lineata*, *R. waageni*, *Productus sumatrensis*, *P. longispinus*, *Richthofenia sinensis*, *Lyttonia richthofeni*, *Orthoceras* cf. *cyclophorum*, *Fusulina cylindrica*, *Rhombopora lepidendroides*, *Aviculopecten M'Coyi*, etc.
This series is sometimes represented by a barren sandstone, as in the vicinity of the Si-hu, near Hang-chou.

b. Middle or Fusulinidea Limestone Series. Bituminous limestone containing layers of flints and many species of *Fusulina* and *Schwagerina* characteristic of the Middle Series of the Anthracolithic Formation.

[1] *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xxi, art. 9.
[2] *China*, vol. iii, p. 521.
[3] Loczy, op. cit., vol. i, pp. 692–746; Suess, *La Face de la Terre*, iii, pp. 277, 293.
[4] Willis, op. cit., vol. i, pt. i, pp. 274–6.
[5] *China*, vol. ii, pp. 600–1.

a. Lower Series. Massive conglomerate and sandstone immediately underlain by a bituminous limestone with Lower Carboniferous fossils, e.g. *Lonsdaleia floriformis*, *L. papillata*, *Zaphrentis spinulosa*, *Syringopora ramulosa*, *Hallia* (*Caninia*) *gigantea*, *Fistulipora minor*.

Richthofen describes a classical section of this series in the Hsi-hsia-shan, near Nan-king.

It is highly probable that these three series do not exactly correspond to those of eastern Yun-nan. Apparently either the whole or the lower part of the Upper Series described here is equivalent to the Middle Series of eastern Yun-nan. That is to say, only the lower part of the Fusulinidea Limestone of south-western China is present in the lower Yang-tze Valley. The upper part of the Lower Series, namely, the conglomerate and sandstone, possibly corresponds in time to the post-Middle Carboniferous and pre-Uralian unconformity already mentioned.

Closely related to the Anthracolithic Formation both in point of time and space, are several series of rocks in China that still evade our classification. In the Sin-tai Basin, western Shan-tung, Blackwelder distinguishes a Sintai Series consisting of sandstones and other kinds of terrestrial deposit. In view of the fact that the Sintai Series overlies the Poshan Series, Blackwelder regards the former as a Permo-Mesozoic formation. Plant-remains that have been obtained from this series generally indicate a Liassic age. The thickness of the series, according to Richthofen, amounts to about 1,400 feet, and according to Blackwelder still less. It therefore appears to be doubtful whether even the lowest part of the Sintai Series should be assigned to the transitional period from the Palæozoic to the Mesozoic. The Supra-coal Sandstone, a barren, massive sandstone overlying the Shansian Productive Measures in many places of northern and north-western China, is in all probability a true Permo-Mesozoic representative. In central China two series of Permo-Mesozoic rocks are known: the one is the Kuei-chou Series,[1] consisting of sandstones, shales with subordinate bands of limestones and layers of coal, and has yielded *Dielasma* cf. *elongatum*, *Aviculopecten* (?) *richthofeni*, crinoidal fragments, foraminiferal tests, *Nilssonia*, *Podozamites*, *Asplenium*, etc. It is frequently exposed in the Ta-ning-ho valley, western Hu-peh and eastern Su-chuan. The other is a coal-bearing shale of Hwang-i-kang,[2] in the lower part of the Liu-ho valley, eastern Hu-nan, where Richthofen collected a peculiar molluscan fauna including the species *Aviculopecten coxanus*, *Pecten alberti*, and several species of *Schizodus* and *Bellerophon*.

About the Carboniferous-Permian rocks in China our knowledge is at present comparatively more advanced, and therefore a more precise interpretation of China's geological history during that period can be here attempted. In the early Carboniferous time the

[1] Willis, op. cit., vol. i, pt. i, pp. 277–83.
[2] Frech, *China*, vol. v, pp. 184–94.

whole of northern China was still a continent being eroded to a peneplain of aged type. A sea of moderate depth surrounded the western and the southern sides of the continent with the coastal line extending from the south of the Bardoun Valley,[1] in Mongolia, to the west of Kan-su, and then sweeping round along the northern side of the present Tsing-ling Range. Thence southward, the sea either spread over the whole area of the Great Red Basin of Su-chuan or only passed along its south-eastern border, and finally entered the province of Yun-nan. In this direction it could not have been very deep, for the sediment that it received was largely terrigenous.

The Lower Carboniferous sea did not rest long in the position as outlined above. Towards the later part of the Dinantian or the early Muscovian epoch it advanced in the north-easterly direction, turning the whole of northern China that had stood as a continent since the Devonian period into a vast ocean.

As the Muscovian epoch drew near its end, geo-dynamical forces made a grand display in the theatre of Central Asia. Folding and thrusting were accompanied by the eruption of andesitic, rhyolitic, and basaltic lava and intrusion of sills and dykes. The whole of western China, from the Nan-shan region to eastern Yun-nan, which had been under the Lower Carboniferous sea, was thereby lifted above the water. The north-eastern part of the country, however, does not appear to have been involved in this revolutionary disturbance. No sooner had the upheaval died out, than the Uralian or the Upper Carboniferous transgression took place; once more western China was submerged under deep water in which flourished a pelagic fauna. The transgression evidently progressed side by side with the formation of the Hercynian Chains, and the separation of the Indo-African Continent from the northern Eurasian Continent. Between these two continents lay the transgressive Uralian water. The fact that the Fusulina Limestone (= Fusulinidea Limestone) stretches across the Asiatic continent from western China to Egypt, i.e. in the equatorial direction, demonstrates with force such a parallel upheaval and depression.

While land and water were undergoing rearrangement in the world at large in consequence of the Hercynian disturbance, the formation of the thick coal was well under its way in northern and central China. After a period of oscillatory movement of the sea-floor during the Permo-Carboniferous time, the sea again started to retreat southwards, carrying with it estuarine conditions and depositing once more coal seams in the south-eastern provinces. Then there followed another mighty movement of orogenic as well as epeirogenic nature.

As the result of the last-mentioned movement, China proper was bodily elevated and secondarily folded probably in the Sinian direction, viz. north-east to south-west. Inland seas covered the north, while lagoons and salt lakes were formed in the south. In these

[1] Wenjukoff, "Calcaire carb. inférieure, etc.": *Verh. Kais. russ. mineralog. Gesell.*, vol. xxv, 1888.

waters were deposited the Supra-coal Sandstone of northern China, the coal-bearing series of eastern Hu-nan, the Permian gypseous deposit of the south-western provinces. Volcanic eruptions broke out at least in three or four different centres, namely, north-eastern Yun-nan, south-eastern Hu-peh, western Shan-tung, and probably in the vicinity of Nan-king. The enormous masses of granite and porphyry in south-eastern China, western Su-chuan, and at a number of localities in the middle Yang-tze Valley at least partly arrived during this period of unrest.

Owing to the shallow water conditions, the pelagic fauna that had flourished during the Middle Permian time was no longer able to survive in China. Littoral forms, however, thrived in places. Their affinities generally indicate the transition of life from the Palæozoic to the Mesozoic. Following such a change of fauna and a corresponding change of flora, the Triassic period gradually set in. Apart from minor stratigraphical breaks, as indicated by local unconformities in the south-western provinces, there appear no signs of remarkable earth-movement in China to define the beginning of the Mesozoic Era.

Triassic and Jurassic.

Mesozoic rocks are developed *par excellence* in the Great Red Basin of Su-chuan and in the areas immediately to the south and east of it. Elsewhere in China they are only known to occur in smaller isolated basins, but are, nevertheless, widely distributed.

With regard to the Trias, very little is known in northern China. If its presence be assumed—we have some reason to do so—its representative must be sought in the upper part of the Supra-coal Sandstone and the similar shallow water or even terrestrial deposits. The rocks are usually destitute of fossils. Only two exceptional cases are known: Obrutchov found, near the village of San-shi-li-pu,[1] Shen-si, *Danæopsis hughesii* (Middle Gondwana) occurring in association with representatives of the *Glossopteris* flora, such as *Neoggrathiopsis hislopi* and *Cordaites* leaves. Brongniart[2] describes a flora collected from Tin-kia-po, southern Shan-si, belonging either to the Upper Trias or to the Lower Jurassic.

In contrast to the case of northern China we have in the south-western provinces several fossiliferous series of Triassic rocks. Information from Kwei-chou and Yun-nan seem to show that the Trias is more or less similarly developed throughout a greater part of these provinces,[3] and generally consists of the following three conformable series:—

Upper Trias. Coal-bearing sandstone followed downwards by soft marls; containing *Trachyceras fasciger*, *Megaphyllites lantenoisi*, *Pseudomonotis plicatuloides*, *Loxonema* cf. *subornata*, *Dictyophyllum exile*,

[1] *Denkschr. Akad. Wien*, vol. lxx, 1901, pp. 139–54.

[2] *Bull. Soc. Géol. France*, sér. iii, vol. xxvii, 1899, pp. 499–520.

[3] Deprat, op. cit., pp. 175–219. Leclère, op. cit., pp. 34–5, 38–9. Koken, *N. J. f. M.G.*, vol. i, pp. 186–215.

Glossopteris indica, Anomozamites inconstans, Clathropteris platyphylla.

Middle Trias. Series of limestones with intercalated marls and a few sandstones, yielding a typical Muschelkalk and St. Cassian fauna, including the species *Naticopsis undularia, Myophoria elegans, Torquemia difformis, Encrinus liliiformis.*

Lower Trias. Variegated marls and sandstones with *Myophoria, Anoplophora, Lingula metensis*, etc.

The succession of the Triassic rocks in the Great Red Basin of Su-chuan and its neighbouring areas appears to be comparable with the above-described sequence, namely, a calcareous series intervening between two argillaceo-arenaceous series.[1] On the northern border of the basin the lower argillaceo-arenaceous series seems, according to Richthofen's report, to be absent.[2]

True marine formation of Lower Triassic age is definitely known in China only in two places[3]: Leclère found a hard, dark limestone near Kwei-yang (about long. 106° 40′ E., lat. 26° 25′ N.) and Kai-tshou (about long. 107° E., lat. 27° N.) yielding fossils that are related to the fauna of the Lower Ceratites Limestone of Indo-China. Futterer observed a limestone containing *Xenodiscus, Lecanites*, and being conformably succeeded downwards by a series of limestones, including the Doliolina Formation.

Jurassic rocks occur[4] in the Sin-tai, Wei-hsien, Putschi basins, western Shan-tung; the Lai-yang Basin, eastern Shan-tung; the Tsaitang and Tatung Basin, northern Shan-si and north-western Chi-li; the Kuei-chou Basin, eastern Su-chuan; the Great Red Basin of Su-chuan; and the Yuan-kiang Valley, Kiang-si. They are generally composed of sandstones and shales frequently intercalated with seams of coal of high economic value. Several varieties of *Podozamites lanceolatus*, together with *Asplenium whitbyensis* and other species of Liassic plant, are of frequent occurrence in the above-mentioned places. Dr. A. Smith Woodward describes several species of *Lycoptera* from Layang-hsien,[5] Shan-tung, and regards them as belonging to the Lower Jurassic.

A Jurassic dolomite containing *Pleuromya* and *Hologyra*? is reported to occur in the Jao-pu district, south of Tchen-ning (Kwei-chou). It attains a thickness of more than 600 feet. According to Leclère the dolomite is underlain, near the Blue River, by a Rhætic coal-bearing series. The limestone that forms plateaus between Kwang-si and Kwei-chou, north of Jao-mong, is tentatively attributed to the same formation.

In the Tatung Basin and on the western border of the Great Red

[1] Abendanon, *Zeits. d. d. Geol. Gesell.*, vol. lix, pp. 197–203.

[2] *China*, vol. ii, p. 603.

[3] Leclère, loc. cit.; Futterer, *Durch Asien*, vol. iii, p. 131.

[4] Lorenz, op. cit.; *China*, vol. ii, pp. 193, 208, 292–9, 351–9; *idem*, vol. iii, p. 104; *Denkschr. Akad. Wien*, vol. lxx, pp. 139–54; *Palæont.*, vol. xxxi, pp. 163–82; *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xxi, art. 9.

[5] *Catalogue of Fossil Fishes Brit. Mus.*, pt. iv, p. 3. The writer believes that the word "Layang-hsien" should be spelt as "Laiyang-hsien".

Basin of Su-chuan the Jurassic rests unconformably upon the older rocks; while inside the Red Basin and in the Kuei-chou Basin it is apparently conformable with the overlying and underlying rocks.

As previously remarked, during the transitional period from the Palæozoic to the Mesozoic a widespread and far-reaching change in physiography and physiographical conditions seems to have induced a rapid evolution of fauna and flora in China as in other parts of the globe. The physical change in China is, however, as a rule, neither indicated by a sharp contrast in the lithological character of the rocks formed during the period, nor by an unconformity which extends over a large area. Subaerial denudation on the lands proceeded simultaneously with the continuous deposition in their neighbouring waters. In this way the several Permo-Mesozoic series were presumably formed.

During the Lower Triassic time the Tsing-ling Range apparently stood well above the rest of the country. Its general trend could not have been very different from what it is to-day. By this range the shallow inland sea in the north was separated from an arm of the open ocean, which covered eastern Su-chuan, western Hu-peh, parts of Hu-nan and Kwei-chou, and eastern Yun-nan.

On the arrival of the Muschelkalk epoch the open Triassic ocean with a pelagic fauna made a decisive move from the Himalaya region towards the north-east, and succeeded, at least, in invading south-western China. The formation of the Middle Triassic Limestone was no doubt due to the introduction of true marine conditions. As the Middle Triassic sea started to retreat towards the south-west, estuaries and lagoons naturally came into existence. In these waters were deposited the Rhætic coal-bearing series. Towards the end of the Rhætic epoch south-western China again started to sink, resulting in the formation of the Jurassic dolomite, but many parts of western China gradually rose above the water. The separation of a huge lake, the Lake of Su-chuan, from the open sea had its initiation in all probability at this time.

The climate was then suitable for the growth of coal-making vegetation, and consequently coal seams were laid down in the lake during the Liassic time. Owing to occasionally excessive evaporation the water in the Lake of Su-chuan became highly saline; eventually seams of gypsum and rock salt were deposited. Under such climatic conditions, and in a water so heavily charged with macerated vegetable matter, it is readily imaginable that minute organisms multiplied themselves at an enormous rate when the water was less saline. Much of the mother substance of the petroleum in Su-chuan may have had its origin in this way.[1] Many of the depressed areas in northern China were likewise covered by inland waters, in which coal-bearing rocks were deposited. The flora that then thrived in China was closely related to that of Siberia and Spitzbergen, showing that these countries were attached to one

[1] W. S. Boulton, Presidential Address to Brit. Assoc. Adv. Sci., Section C, Newcastle-on-Tyne, 1916, p. 12.

and the same continent—the Angara Continent [1]—in the Jurassic time.

Post-Jurassic.

The period extending from the latter part of the Jurassic down to the present day is poorly represented in China by sedimentary record. The occurrence of a few *Unio* and *Cyrena* related to the Wealden fauna,[2] and one or two species of Cretaceous ? plants [3] in the Great Red Basin of Su-chuan, makes it highly probable that the Cretaceous period is there represented by a series of sandstones and clay-rocks as reported by Richthofen, Abendanon, and Cremer from eastern Su-chuan. This series is underlain by the coal-bearing Jurassic formation and overlain by a group of red sandstones of Tertiary age. No marine Cretaceous formation has been found in China proper, nor does it seem to occur in that part of the world.

Tertiary and Quarternary rocks are widely distributed in China, and attain a considerable thickness in places. With respect to their lithology, five groups are recognizable. They are enumerated below irrespective of the order of their formation :—

(1) Coal-bearing, sandy, and clayey rocks occurring in the graben of the Liao-ho, Manchuria ; and in the Mong-tzeu and other basins, Yun-nan.

(2) A group of red sandstones, known as the Young Red Sandstone, often containing intercalated marly layers and basal conglomerate ; widely distributed all over the Great Red Basin of Su-chuan, in the provinces of Hu-nan, Kwei-chou, Kwang-tung, Kiang-si, An-hwei, Hu-peh, Ho-nan, Shen-si, Kan-su. They are reported to occur on the high mountains of the Tsing-ling and in the valleys of the Nan-shan. Several local names have been proposed : Loczy calls it the Flysch-like sandstone in the mountainous area of western Su-chuan, Richthofen calls it the "Cover Sandstone" (Deckesandstein) in the province of Hu-nan. These rocks generally strike east–west or north–south except in the intermontain valleys of the high ranges where its dip, as a rule, conforms with the slope of the range against which it laps. Mammalian remains, largely belonging to the Pliocene but rarely to the Quaternary,[4] are frequently found in the bedded rocks of this series or in the caves formed in it.

(3) The Gobi or Han-hai [5] Series consisting of soft sandstones, clays, and loose conglomerate ; well developed in north-western China and Mongolia ; merging, in some cases, into the Young Red Sandstone.

(4) A conglomerate significantly developed on the down-throw sides of great normal faults in northern China, e.g. in the Ning-shan Basin, Shan-si, and in the Wen-ho Valley, Shan-tung. Willis and Blackwelder name it the Wen-ho Conglomerate.[6]

[1] Suess, *The Face of the Earth*, vol. iii, p. 19.

[2] Frech, *China*, vol. v, pp. 221–5.

[3] *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xxi, art. 9.

[4] Owen, "On Fossil Remains of Mammals found in China" : *Quart. Journ. Geol. Soc.*, vol. xxvi, pp. 417–34. Schlosser, "Die fossilen Säugethiere Chinas" : *Centralbl. f. M.G.*, 1902, 529–35 ; *Abh. K. bay. Akad. Wiss.*, vol. xxii, 1903, pp. 1–221. Koken, "Ueber fossile Säugethiere aus China" : *Palæont. Abh.*, vol. iii, 1885.

[5] *Peter. Mitt.*, vol. xlvi, 1900, pp. 22–3.

[6] Willis, op. cit., pp. 57–8.

(5) The Loess or Hwang-tu composed of a soft, homogeneous, clayey material often with suggestions of stratification, occasionally interbedded with sands and clays; capping high mountain ranges and forming extensive plains in northern China. The structure of the Loess is singularly vertical; for instance, peculiar tubes sometimes as small as rootlets and sometimes as large as organ pipes frequently traverse the rock upwards and downwards.

Continental China has experienced much change since the later part of the Jurassic time. The succession of the more important events is briefly as follows: As the Jurassic seas receded both northward and southward from China proper, forces of denudation began to operate in full swing. Mountain ranges in central China were to a large extent planed down. The material thus produced was washed off into the neighbouring valleys and basins, such as the Great Red Basin of Su-chuan and others. The whole country, which presumably possessed a strong relief in the early part of the Jurassic period, gradually became a vast expanse of tableland. By the Cretaceous time China proper was completely reduced to a mature peneplain. Nevertheless, a broad epeirogenic swell seems to have continued to uplift the country in a steadfast manner, for even the world-wide Cenomanian transgression did not invade China any further than the southern part of Tibet.

Towards mid-Tertiary time the prolonged tranquillity was broken by a violent attack of orogenic movement from the south. The Alps of the Himalaya rose to a great altitude to the west of China; the Tsing-ling and Nan-ling ranges attained their lofty attitude across the central and the southern part of the country; large blocks of strata were faulted down in northern China to the extent of 10,000 feet or more; fissures or vein eruptions ejecting enormous quantities of basaltic lava were rampant in southern Mongolia, Shan-tung, and northern Kiang-su, answering to their comrades that were then fully active in Iceland and north-western Britain. Thus the process of erosion once more became vigorous.

The scenery of China was then quite different to the aged peneplain of the Cretaceous and early Tertiary time. Salt basins and intermontain lakes existed in all provinces. Such a varied type of scenery and other physical conditions evidently attracted the wandering beasts from various parts of the globe. The plateaus and open plains were peopled by the *Hipparion* fauna, while the forests and swamps were inhabited by the *Suidæ* or deer and swine-like animals. Their ancestors may have lived in Europe and North America, as shown by the presence of antelopes, *Cervus*, *Tylopoda*, etc., and their allies certainly scattered all over India and Persia.

Inevitably the lakes and basins were rapidly filled up by material derived from the mountains and highlands resulting in the formation of the Young Red Sandstone. Side by side, the deposition of the Gobi Series in north-western China turned the shallow inland sea into a vast plain dotted over with a large number of saline lakes. This region well deserves the name "Han-hai" or the Dry Sea.

As the result of the disappearance of inland waters, the atmosphere of northern and north-western China became arid. At the end of the Pliocene or the beginning of the Pleistocene time aeolian conditions prevailed. The decomposed rock-material was blown about and spread far and wide over hills and valleys. Thus the formation of the Loess began, and has continued down to the present day. It is uncertain whether there was a general lowering of temperature during this period in China [1] as in north-western Europe and North America; for even if the climate was severely cold, the aridity of the atmosphere could not have allowed the existence of large glaciers. The absence of a large mass of ice in Eastern Siberia to-day, in spite of the Arctic temperature, well illustrates such a case.

Since the mid-Tertiary movement hypogene geological forces have by no means become dormant; for we clearly see that the Young Red Sandstone and even the river deposit in the lower Yang-tze Valley are generaliy tilted. According to Mr. V. K. Ting the Loess in the Ssue-hua-shan and other districts, south-western Chi-li, is affected by a basaltic igneous rock. Apart from such stratigraphical evidence there is to be noted another class of phenomena—phenomena belonging to the physiographical domain—which, when carefully analysed, would undoubtedly throw light upon the problem of recent earth-movement in China. For the want of space, here we can only refer to one or two important points.

Let us follow for the moment the courses of the Hwang-ho and the Yang-tze-kiang. The fact that both of these rivers flow in their middle courses towards the central mountainous area, the Tsing-ling Range, is sufficiently significant to claim our consideration. If Pumpelly's diagram [2] illustrating the prehistoric course of the Hwang-ho be based on good authority, then the Hwang-ho must have travelled at one time through northern Shan-si and north-western Chi-li. The huge delta that spreads in front of small streams from the mountains to the north-west of the Plain of Peking, as described by G. F. Wright,[3] appears to signify the previous existence of a powerful river, and therefore may be taken as a specific feature that tends to support Pumpelly's hypothetical diagram. Along the northern foot of the Ta-hwa-shan the Loess is apparently affected by the Ta-hwa fault which is, without doubt, a continuation of the famous Wei-ho fault. It then seems highly probable that the southerly course of the middle Hwang-ho has been determined by an uprise in north-eastern Chi-li and the downthrow of the Shansian block against the Tsing-ling Range, owing to the continued development of the Ta-hwa-Weiho fault. The "Universal Deluge" in northern China, before Emperor Yue (about 2700 B.C.) accomplished his great engineering feat at Long-menn (about long. 100° 10′ E.,

[1] Cf. Geikie, *The Great Ice Age*, p. 402.
[2] Pumpelly, op. cit., pl. v, map xi.
[3] *Quart. Journ. Geol. Soc.*, vol. lvii, p. 244.

lat. 34° 40′ N.), might have been partially due to such a dramatic physiographical change that had upset the pre-existing drainage systems. The fact that ancient seaports on the coast of Pe-chi-li are now found many miles inland is also in favour of this argument.

In the eastern part of the Great Red Basin of Su-chuan the Yang-tze flows towards north-north-east in spite of the increasing mean altitude of land towards that direction. Clearly then the middle part of the river, which cut into the late Tertiary or even Quaternary sandstones, must be antecedent to the recent upheaval of the Tsing-ling area.

It is hoped that these working hypotheses drawn from very incomplete data may serve to arouse the interest of field geologists, by whose accurate record of detailed observations alone the question of their acceptance or rejection may be finally settled.

In spite of the great demand of space, the writer cannot let this opportunity pass without expressing his gratitude to Professor W. S. Boulton for his college training, especially during the preparation of a thesis of which the present paper is a precis; and his obligation to Dr. L. J. Wills, M.A., who cordially made several valuable suggestions and criticisms relating to the arrangement of material in this paper before it was put in the present form.

Morphological Studies on the Echinoidea Holectypoida and their Allies.

XI. *CONULOPYRINA ANOMALA*, A NEW TYPE OF THE *ECHINONEIDÆ*.

By HERBERT L. HAWKINS, D.Sc., F.G.S., Professor of Geology, University College, Reading.

(PLATE VII.)

AMONG the Echinoids from the Limestone Lenticles of Shenley Hill (Leighton Buzzard), sent to me from the Sedgwick Museum, Cambridge (see GEOL. MAG., Vol. LVIII, 1921, p. 57), one specimen of the many Pyriniform examples at once attracted attention by its preservation, relatively large size, and superficial resemblance to *Holectypus*. A brief comment on the specimen (No. 3 of the series) was made in the note already cited; further and more detailed examination, preceded by removal of matrix, has revealed additional features of much interest. Though averse to diagnosis of new genera or species based on single specimens, I have felt compelled to adopt that course in this case, in default of acquaintance with any described types to which the Shenley Echinoid could be assimilated. It is quite likely that other specimens, congeneric if not conspecific, may exist in collections; according to their preservation or the idiosyncrasy of individuals they may be labelled *Holectypus*, *Conulus*, or *Pyrina* with equal probability. It is even possible that some of the numerous species of *Pyrina* (including *Pseudopyrina*

and *Globator*), already described, may be referable to the genus here introduced; but more details of morphology than are often supplied in systematic diagnoses and figures are needed before order can come out of the chaotic series of Cretaceous Echinonëidæ.

I am convinced that the shape of the test is a feature of practically no importance in specific determination in the group; while even the position of the periproct is reliable only when specimens of the same size from accurately determined horizons are compared. The apical system shows a remarkable constancy of structure throughout the family, and so is useless for detailed taxonomy. The obliquity or symmetry of the peristome is another morphological character often invoked as a generic criterion; but I have yet to find a specimen of *Conulus* without some degree of asymmetry in that aperture. There remain but two external characters for comparison, the surface-ornament and ambulacral structure. Both of these demand good preservation for detection, and patient study for appreciation; the latter attribute has too often been lacking in descriptions (and particularly in drawings) purporting to represent these details.

In the note introductory to this series of papers (GEOL. MAG., 1917, p. 161), I laid emphasis on the essential conservatism of the Holectypoida, and the systematic difficulties thereby engendered. In no family of the order is this static quality of essentials more manifest than in the Echinonëidæ. No investigation that does not take into account stratigraphical and morphological features more delicate than suffice in some other groups can have much hope of success. It is with delight that I learn that my friend Dr. A. W. Rowe is following up his classic study of *Micraster* with a similar treatment of *Conulus*. In that way alone can the continuous or gently oscillating course of evolution of pelagic Echinoids be traced. But for the relatively littoral types, among which *Pyrina* must be classed, disjointed fragments of history are alone available; so that every detail needs accurate description, lest an inconspicuous feature that later proves a reliable guide should be overlooked. Thus, and thus only, may it be possible for some future worker to ascertain the distinctive characters of *Conulus* and *Pyrina*, which Lambert places in separate orders, while I cannot undertake to point out even generic differences that apply to all of the species therein included.

In respect of the two characters above indicated as possessing taxonomic value, it seems possible to find a rough distinction between *Conulus* and *Pyrina* in the following comparison. The interambulacral tubercles of *Conulus* are relatively small, with shallow areolæ, adapically; and larger, with deep areolæ, on the ambitus and adorally. Those of *Pyrina* are less distinctly differentiated, the tubercles of both surfaces being fairly large and the areolæ narrow but deep throughout. In both genera a chevron pattern is developed by the tubercles of each interambulacral plate, but in

Conulus there is a marked tendency for the downward (i.e. orad) sloping lines to consist of three tubercles in series (chiefly on the adapical surface), while in *Pyrina* they rarely comprise more than two. Thus the tuberculation of *Conulus* often appears somewhat irregular, while that of *Pyrina* consists of two regular transverse rows of tubercles on each plate. The ambulacral plates are grouped into triads almost throughout the areas in both genera, but the pore-pairs take on a triserial arrangement near the peristome in *Conulus*, and are practically uniserial in *Pyrina*. Because the form about to be described resembles *Pyrina* in tuberculation (though showing certain differences of detail) and *Conulus* in pore-disposition (though in an exaggerated manner), I have named it

CONULOPYRINA.

Holectypoida, Echinonëidæ (*sensu* Hawkins, 1920, non Lambert, 1918) ? Conulinæ.

Test oblong-oval; adapical surface tumid, apex central; adoral surface rounded, tumid posteriorly, peristome slightly invaginate; ambitus rounded. Peristome slightly elongate, about 0·18 of test-diameter. Periproct marginal, rounded adorally, sharply acuminate adapically. Apical system as in family. Ambulacra lanceolate, widening rapidly but evenly from apex to ambitus, slightly convergent adorally; plates apparently with Pyrinid triad grouping almost throughout. Pore-fields very narrow adapically, very faintly impressed; pore-pairs uniserial on adapical surface, definitely triserial from ambitus to peristome. Interambulacra about 2·5 times width of ambulacra on ambitus—each plate corresponds to about five ambulacral plates adapically, and about seven adorally. Primary tubercles arranged as in *Pyrina*; little additional ornament adorally, but greater parts of adapical surface occupied by crowded secondary tubercles and granules of various sizes, but with no scrobicular arrangement.

Genotype.—*C. anomala* sp. n., ? Cenomanian, Shenley Hill. (Pl. VII.)

Description of the holotype (Sedgwick Museum, Walker Coll., "1905." "No. 3," Hawkins, Geol. Mag., Vol. LVIII, 1921, p. 58).

Measurements.—Antero-posterior diameter, 28·5 mm. = 1; transverse diameter, 27·0 mm. = 0·95; height, 14·5 mm. = 0·51; peristome (approximate diameter), 5·1 mm. = 0·18; periproct (long diameter), 8·0 mm.; periproct (transverse maximum diameter), 5·5 mm.; apical system (ant.-post. diameter), *c.* 2·3 mm.; ambulacra (width on ambitus), 4·7 mm. = 1. Interambulacra (width on ambitus), 12·0 mm. = 2·55.

Number of ambulacral plates (area III*a*), 103 (45 on adoral surface, 58 on adapical surface).

Number of interambulacral plates contiguous to above, 22 (10 adoral, 12 adapical).

Ambital outline ovoid, obtusely angular (Pl. VII, Figs. 1 and 2)

Transverse diameter greatest at ambulacra II and IV (which form blunt angles), thence lessening gradually to areas I and V (which are not at all prominent). A slight posterior elongation in area 5 is slashed by the marginal periproct. Adapical surface evenly convex, slightly flattened at apex. Ambitus rounded, ill-defined; there is no "posterior surface" (Pl. VII, Fig. 3). Adoral surface concave for the inner two-thirds; ambulacra hardly impressed, interambulacra very slightly tumid, except 5, which forms a marked protuberance below (i.e. orad to) the periproct (Pl. VII, Figs. 3 and 4).

Peristome not very clearly shown (? imperfect), slightly longer than broad, apparently oblique in the direction 3–I, but with an asymmetrical bay in II (? due to fracture). Invagination faint, being a continuation of the curvature of the adoral surface.

Periproct (Pl. VII, Fig. 3) large, strictly marginal, forming a marked indentation in the ambital outline, as seen from either surface. Rounded adorally, greatest width on ambitus, sharply acuminate adapically.

Apical system (Pl. VII, Fig. 5) small, approximately central, truncating the apex of the test. Four relatively large genital pores arranged in a trapezium with the posterior pair more widely separated (3 and 4 lie parallel to the antero-posterior axis, 1 and 2 make an angle therewith). Plates arranged as in *Pyrina* or *Conulus*, but contiguous posterior oculars subequal.

Ambulacra (Pl. VII, Fig. 7) similar, with simple pores throughout; I and V form a recognizable "bivium". Adradial sutures practically straight, sharply divergent adapically, subparallel on and above the ambitus, gently convergent adorally. Areas hardly inferior in width to interambulacra on peristome-margin. Plate-structure typically Pyrinid, wherever visible. Pore-fields very narrow adapically, with close-set, uniserial pore-pairs in faintly sunken peripodia; widening rapidly just below the ambitus, with strongly triserial pore-pairs (? without peripodia) over almost all the adoral surface. Pores uniformly minute. Major ornament in each column consisting of an external primordial row of tubercles continuous from peristome to apex (much reduced in size towards the ambitus); a second row (with very large tubercles adorally) extending from the fifth primordial tubercle to a point rather nearer the ambitus than the apex; and a third, internal, row (large below the ambitus) extending from the middle of the adoral surface to a point considerably above that reached by the second, with a few scattered members quite near the apex. Rows one and three are situated on the largest plates of the triad-groups, row two on the smaller primaries.

Interambulacra (Pl. VII, Fig. 7) slightly dissimilar, 2 and 3 being a very little less wide than 1 and 4; while 5 is distinctly narrower (though not carinate) and strongly inflated below the periproct. Plates remarkably even in height throughout, those around the ambitus being very slightly lower than the rest. Major ornament in

each column consisting of an almost median primordial row placed towards the adoral margins of the plates (except near the apex), continuous from apex to peristome, relatively small just below ambitus, and there accompanied by occasional orad supernumeraries. Radiad and interradiad rows introduced with some regularity (after about the third plate from peristome or apex), alternately near the apicad and orad margins of the plates, forming fairly regular transverse rows, the primordial tubercles entering the orad row of each plate. Five tubercles on each side of the median one is the rule for ambital plates, but occasionally more occur by development of three in place of the normal two in the oblique series.

Tuberculation (Pl. VII, Figs. 6 and 7), consisting of primary and secondary tubercles, and granules that sometimes appear almost tertiary tubercles. Primary tubercles with convex bosses and small perforate mamelons; areolæ always deep, but most noticeable adorally, where (from the ambitus) they become relatively large, occupying the greater part of the test-surface. Adapically the primary tubercles are comparatively small (much more so than in most species of *Conulus* or *Pyrina*) and rendered the less conspicuous by the strong development of secondaries. Secondary tubercles very numerous on adapical surface, with marked though shallow areolæ, giving a shagreen-effect above the level of the primaries. Scrobicular grouping around primaries not evident. Intervening space packed with granules (which may occasionally possess areolæ), adding to the extreme roughness of the adapical surface. No certain evidence of "sunken" or glassy tubercles, though in places impression of sand-grains gives suggestion of existence of the former.

The only specimen at present known was collected from the "Limestone Lenticles" at Shenley Hill, near Leighton Buzzard, Bedfordshire. The horizon of these lenticles is a matter of controversy, but the palæontological evidence points fairly conclusively to their Cenomanian age—perhaps correlating them with the subzone of *Catopygus columbarius* at the base of the zone of *Schlœnbachia varians*. (The alternative reading of the section would locate the horizon in or about the Lower Gault.)

Discussion of Affinities.

In the preliminary note (Geol. Mag., Vol. LVIII, 1921, p. 58) I drew attention to the marked resemblance of the specimen to an *Holectypus* with marginal periproct, mentioning the Lower Oolitic species *H. hemisphæricus* in particular. The appropriateness of this comparison will be obvious to anyone who handles the specimen; but there are few features of real importance in which it is worth emphasizing. In essentials *C. anomala* is emphatically *not* one of the Holectypidæ, for it has no fifth genital, and its interradial tuberculation is double on each side of the median row; whereas in *Holectypus* there is always a fifth genital, perforate in Cretaceous types (*Coenholectypus*), and the interradiad tubercle-series form single transverse

lines on each plate. But the extreme smallness of the primary tubercles of the adapical surface, and the wealth of simple secondary tuberculation and granulation there, coupled with the rapid increase in size of the primaries at and orad to the ambitus, are of such a quality that *Holectypus* rather than *Conulus* (still more than *Pyrina*) affords the nearest comparison. But such a character (indicative of difference in size of the radioles on the two surfaces) is more likely to be adaptive than intrinsic, and so can hardly be invoked as involving close affinity. Again, the shape, size, and position of the periproct are all comparable with those features in *Holectypus*.

The points of chief importance wherein *Conulopyrina* differs from all other Echinonëidæ (*sensu meo*) are: the prolongation of triserial arrangement of the podial pores over the entire adoral extent of the ambulacra, the position of the periproct (roughly intermediate between *Conulus* and *Pyrina*), and the quality and pattern of the surface ornament of both areas. *Pileus* is the only Holectypoid in which the pore-pairs show comparable departure from the uniserial plan (both in quality and extent), but there is no other apparent reason for suggesting any close relationship between the two genera. The position of the periproct is certainly suggestive of a stage midway between *Pyrina* and *Conulus*, but the known migration of this aperture in ontogeny makes it unsafe to give *Conulopyrina* such a phyletic place, since only one example is available. It is, however, far from impossible that this may be its true interpretation.

The order of appearance and disappearance of the main tubercle-rows on the ambulacra is very strange. That the primordial continuous row should be external (adradiad) is normal for the order, although the reduction of its members to almost secondary rank on the adoral surface is unusual. The situation of the second row on the alternate primaries is normal, but the disappearance of this series adapically while the third row still persists is quite anomalous.

The arrangement of the interradial primary tubercles is fairly typical of that found in *Anorthopygus* or *Pyrina*, but there are more unituberculate plates than is usual in the Echinonëidæ. However, the extraordinary congestion of the minor ornament on the adapical surface, coupled with the great reduction in size of the primaries in that region, seem unique for the Holectypoida, and can best be compared with the granulation of such Caratomids as *Conulopsis* ("*Echinoconus*" of Lambert). This comparison is emphasized by the maintenance of sunken areolæ in the reduced apicad tubercles; but I should hesitate to suggest any phyletic meaning in the character, especially in view of the great contrast in ambulacral structure between *Conulopyrina* and *Caratomus*.

To sum up, *Conulopyrina* is definitely a member of the Echinonëidæ (as I interpret the family). It is neither a *Conulus* nor a *Pyrina*; it possesses some of the characters of both these groups, and others present in neither. Its resemblance to *Holectypus* is most probably

a case of "heterogenetic homœomorphy", perhaps induced by similarity of habitat. On the evidence at present known, I am inclined to consider it as representing either the common stock from which both *Pyrina* and *Conulus* arose (though not by any means the actual radicle itself), or else as an offshoot from the *Pyrina* stock parallel to the *Conulus* line, but overreaching the *Conulus* stage.

EXPLANATION OF PLATE VII.

Fig. 1.—*Conulopyrina anomala*. Adapical view. Natural size. All ornament omitted in this and three following figures.
Fig. 2.—*Conulopyrina anomala*. Adoral view. Natural size. The actual peristome margin is obscure in the original; see text.
Fig. 3.—*Conulopyrina anomala*. Posterior view. Natural size.
Fig. 4.—*Conulopyrina anomala*. Side view. Natural size. The broken line near the bottom of the figure represents the peristomal concavity of the adoral surface.
Fig. 5.—*Conulopyrina anomala*. Apical system enlarged.
Fig. 6.—*Conulopyrina anomala*. Detail of parts of the adapical surface midway between apex and ambitus, taken in a place where the sutures of the ambulacrals are visible.
Fig. 7.—*Conulopyrina anomala*. Area III and contiguous interambulacral columns. Only primary tubercles shown. Ambulacral plating not inserted, but occasionally determinable as "Pyrinid" on both adoral and adapical surfaces. The broken curve across the figure is the line of the ambitus.

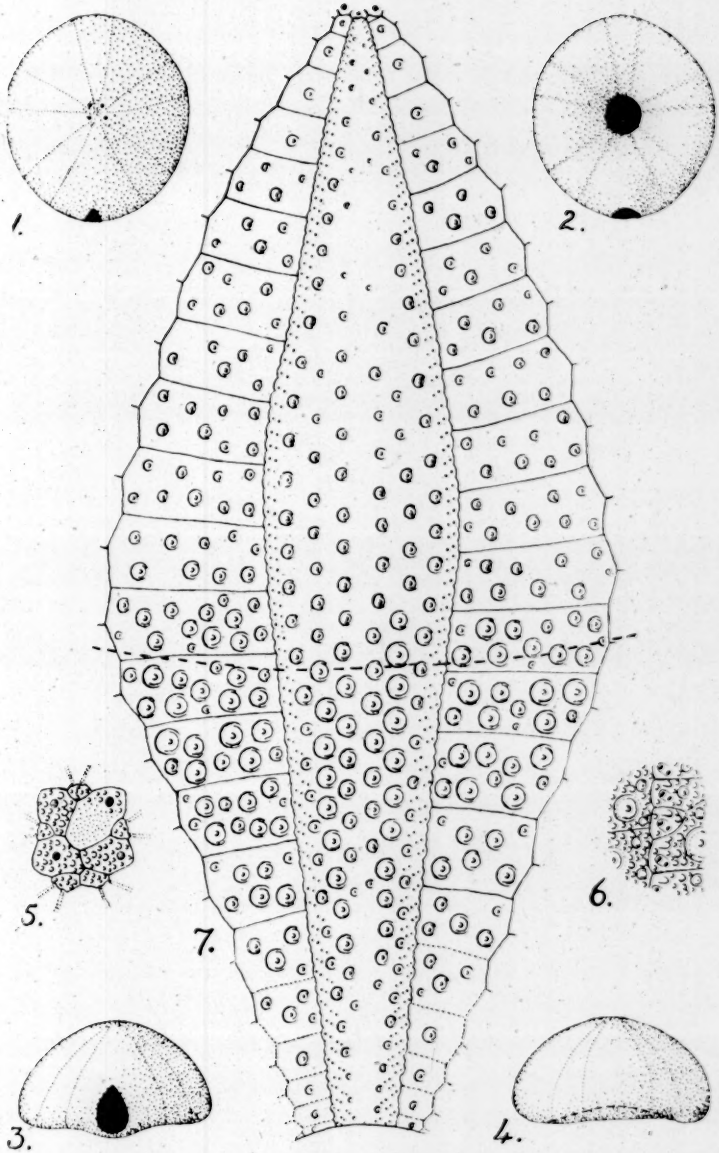
Ammonites from the Upper Lias, Railway-cutting, Bloxham, Oxon.

By L. Richardson

IMMEDIATELY east of Bloxham Station is a cutting through the Marlstone and basement beds of the Upper Lias. The Liassic deposits are now for the most part hidden by vegetation, but when the line was made and for some years subsequently large numbers of fossils—principally ammonites—were collected from them. Several geologists have published particulars concerning the section.[1] The writer has in his collection a number of ammonites from here, which have been examined by Dr. A. E. Trueman. The object of this communication is to place on record the result of his examination.

First, however, some particulars—mainly derived from accounts published by previous authors—may be given. The cutting is through the Marlstone and basement beds of the Upper Lias. At one place the beds are faulted, and about 3 feet of the "Sandy Beds" of the Middle Lias were exposed beneath the Marlstone. The Marlstone is about 24 feet thick. No traces have been observed here of

[1] T. Beesley, *Proc. Geol. Assoc.*, vol. v (1877), p. 168; T. Wright, "Monograph of the Lias Ammonites of the British Islands," *Palæont. Soc.*, pt. iii (1880), p. 128; E. A. Walford, *Quart. Journ. Geol. Soc.*, vol. xxxix (1883), p. 229; *Proc. Geol. Assoc.*, vol. xiv (1895), p. 177, "The Lias Ironstone of North Oxfordshire," Banbury and London (1899), p. 14; H. B. Woodward, "The Jurassic Rocks of Britain, vol. iii—The Lias of England and Wales (Yorkshire excepted)," *Mem. Geol. Surv.* (1893), p. 269.



H. L. H. del.

CONULOPYRINA ANOMALA, gen. et sp. nov.

[To face p. 136.

the Transition Bed (*acuti* hemera), Paper Shales (*tenuicostati* hemera), or Fish Bed (*exarati* hemera). A thin bed of Upper Lias limestone, of *falciferi* hemera, immediately succeeds the Marlstone and may be best described as "welded on" to it. This limestone is succeeded—according to H. B. Woodward [1]—by

"Blue and grey marly clay with thin bands of grey ferruginous nodular earthy limestone. *Ammonites communis, A. bifrons, A. serpentinus*, etc."

Above comes the Cephalopoda Bed of certain local authors. This bed is 5 inches thick, and in places is a ferruginous oolitic limestone. It has yielded *Frechiella* aff. *subcarinata* (Young & Bird), and is of *subcarinati* hemera. Resting on the last bed and occupying hollows in its surface is a thin layer, barely half an inch thick, made up entirely of crinoidal remains. Of this layer Mr. E. A. Walford has written :—

"Thin and inconspicuous as the crinoidal stone is, I have traced it over the country ten miles north of Banbury, where below it are seen the Fish Bed and the Transition Bed. . ." [2]

Clays, measuring some 15 feet, complete the section. They are of *fibulati* date. The total thickness of the Upper Lias in this neighbourhood is about 70 feet. The deposit above the "crinoidal stone" is probably clay only, and the whole of *fibulati* date. Unfortunately, there are not any exposures of use in the vicinity.

As the result of his examination of the ammonites, Dr. Trueman reports :—

"It has not usually been possible to assign specific names—several new species are no doubt included. The specimens are in many cases identical with those I have from Grantham and undoubtedly they indicate the presence of beds similar to those that are so fossiliferous there.

Judging from my experience there, I should say that the *Falciferum*-? *Pseudovatum*- and *Subcarinata*-Zones are represented, with quite possibly the *Fibulatum*-Zone (judging from the *Pseudolioceras*)."

The following is the list of the ammonites :—

Caloceras aff. *fonticulum* (Simpson).
,, sp.
Dactylioceras cf. *acanthus* (d'Orbigny).
,, *commune* (J. Sowerby).
,, cf *commune* (J. Sow.).
,, cf. *commune* (J. Sow.). Stout form.
,, cf. *graciie* (Simpson).
,, aff. *semicelatum* (Simpson).
,, sp. Intermediate between *Peronoceras holandrei* (d'Orb) and *D. commune* (J. Sow.).
Frechiella aff. *subcarinata* (Young & Bird). A little more slender than the type.
Harpoceras connectens (Haug.).
,, aff. *falciferum* (J. Sow.)

[1] "The Jurassic Rocks of Britain, vol. iii—The Lias of England and Wales (Yorkshire excepted)," *Mem. Geol. Surv.* (1893), p. 269.
[2] *Proc. Geol. Assoc.*, vol. xiv (1895), p. 178.

Hildoceras walcotti (J. Sow.). Common.
,, aff. *walcotti* (J. Sow.). Common.
,, cf. *hildense* (Young & Bird). Fairly typical, but furrow too deep for type.
Harpoceratoides sp. Identical with a form in the *Falciferum*- and *Pseudovatum*-Zones at Grantham.
? *Peronoceras* sp.
Pseudolioceras cf. *boulbiense* (Y. & B.).
,, cf. *multifoliatum* (Simpson).
Thysanoceras aff. *cornucopia* (Y. & B.). Smooth form.

REVIEWS.

PREHISTORY: A STUDY OF EARLY CULTURES IN EUROPE AND THE MEDITERRANEAN BASIN. By M. C. BURKITT, M.A., F.G.S. With a short preface by L'Abbé H. BREUIL. pp. i–xx, 1–438, and 47 plates. Cambridge University Press, 1921. Price 35*s*.

FOR a long time the view that man appeared after the Glacial period, at any rate in Europe, was unhesitatingly accepted, but of recent years this view has been challenged, though we have as yet no unanimity of opinion as to the definite relationship of the various civilizations to the Glacial period.

As the result of recent research we must readjust our ideas, and new books necessarily arise. Prominent among them in this country is Sollas' scholarly work *Ancient Hunters* and W. B. Wright's stimulating treatise on the *Quaternary Ice Age*, and now Mr. Burkitt has written a book which "must be regarded as an attempt to give a general idea of the subject" of prehistory, the greater part of which is devoted to the Palæolithic period.

Though the whole of the book is of interest to geologists, they will naturally turn at first to Chapters II and III, dealing with "Geological Conditions" and "Man in Relation to Geology". In Chapter II the author divides the whole history of the world into an introduction succeeded by five volumes, of which the recent period represents volume v. It would have been well if he had warned the general reader that the volumes are far from being of equal importance as regards lapse of time. He next gives an account of the classification of the Pliocene and Pleistocene accumulations. The origin of the Ice Age is dealt with at some length. This seems hardly necessary when we consider our real ignorance of the causes of secular changes of climate and the space thus occupied might well be devoted in a later edition to a fuller discussion of geological matters bearing more directly on the subject. In Chapter III the author boldly sets forth to trace the relations between the various archæological divisions and those put forward by geologists. He is obviously strongly influenced by researches of foreign writers in districts which he has himself visited, and, indeed, it is most necessary to take account of these. The correlations favoured by Mr. Burkitt may well be correct, but as they are in opposition to the views of a number of geologists who have made detailed studies of our British Pleistocene and Holocene deposits, it would be well to take some notice of these views, even though they frequently conflict with one another; furthermore, it might have been mentioned that hitherto no instance has been recorded in Britain of any undoubted Lower Palæolithic implement extracted from a deposit overlain by indisputable boulder-clay, though some artefacts found by Reid Moir below boulder-clay at Ipswich may even be proto-Mousterian. In future the author will probably speak with less uncertain note of artefacts from the Red Crag.

A chapter on flint-fracture and palæolithic tools contains an account of the principal kinds of tools and reference to the characteristic tools of different periods, which are more fully considered in succeeding chapters, which treat of these periods in greater detail. Plates I – V give illustrations of various implements and the reader would no doubt wish to have more frequent reference to these plates in the text.

Chapter XIV is entitled "Prehistoric Man", and the author gives only "a short general epitome of the various prehistoric races, without much special reference to the physical differences in their anatomy". This is a difficult task, and the chapter suffers from undue condensation.

The latter part of the work, from page 192 onwards, is devoted to prehistoric art. Here the author is at his best. He has himself seen most of what he describes, and the reader will follow this portion with keen interest.

Mr. Burkitt must be warmly congratulated on this book. It will be read with pleasure and profit, and is a storehouse of information for purposes of reference. It has been suggested above that at times he goes further than our present knowledge warrants, but one recognizes in this the sign of his intense enthusiasm. No doubt alterations will be made in later editions as the result of future work, and at the same time several little slips which have escaped notice during proof-reading will be altered. That future editions will be called for seems certain, for the book is a worthy addition to the literature of the science.

J. E. M.

A Manual of Seismology. By Charles Davison. pp. xiii + 256. Cambridge University Press, 1921. Price 21*s*.

THE study of earthquakes has always been regarded as essentially a branch of geology: it is a subject on which the impress of English workers is predominant, yet since the appearance of the last edition of the late John Milne's brilliant, though almost unarranged, handbooks, now a full generation ago, there has been no satisfactory manual of the study of earthquakes in the English language. Modern seismology has run principally to the study of the long-distance records of great earthquakes, a subject which is interesting, but has little or no geological application. Dr. Davison's manual, being one of a professedly geological series, devotes but a small section to this modern development of the older seismology, and is almost wholly devoted to the earthquake proper, which can be felt and causes visible damage. To the study of this branch of geology it will serve as a useful introduction, covering the ground in a satisfactory manner, and at the same time giving ample indication of the works which need to be studied by those who wish to go deeper into the subject. It might, perhaps, be thought that an undue amount of space is devoted to small and feeble earthquakes,

but these are vastly more numerous and, when the study of them is more complete, may prove to have as great geological importance and interest as the more sensational, and, at present, more fully studied, destructive shocks. We regret the omission of reference to Col. Harboe's speculations on the nature of earthquake origins, as his studies seem to open up a line of research which is likely to lead to important results; and we notice that Dr. Davison, like almost every other writer, has failed to detect the logical flaw in Dutton's method of determining the depth of origin, which results from the two-fold meaning attached to the word intensity, used in the formulæ as a measure of the amount of energy transmitted over a unit of area in a unit of time, and in the application as synonymous with the acceleration of wave-particle. These are the only omissions of importance which we have noticed in a well-written, well-balanced, and adequate manual of a subject for which such an introduction was wanting and much needed.

The Mineral Industry of the British Empire. Imperial Mineral Resources Bureau Handbooks: Manganese, pp. 151, 3*s.* 6*d.*; Tungsten, pp. 44, 1*s.*; Coal, Coke, and By-Products, pp. 124, 3*s.* 6*d.*

THESE pamphlets continue the plan of the preceding issues. Besides the necessary statistics the monographs on manganese and tungsten contain useful accounts of the geology and mineralogy of the deposits, with excellent bibliographies in each case. The volume on coal and its products deals mainly with statistics and the properties of different coals as fuel, and there is little to interest a geologist.

The Iron and Associated Industries of Lorraine, the Sarre District, Luxemburg, and Belgium. By A. H. Brooks and M. F. La Croix. Bull. 703, U.S.G.S., pp. 131, with 2 plates and 12 text-figures. 1920.

THIS bulletin is mainly metallurgical, statistical, and political, but it includes a clear though brief account of the geology of the iron fields, which should be of value to those interested in the subject. There is a good bibliography, and a most useful feature is a large-scale folding map showing the geographical position of the iron and coal fields and their relation to the great industrial districts of Western Europe. The latest estimates show that France has now control of 48 per cent of the European iron-ore reserves, and for many years to come the Lorraine iron field must continue to be a dominant factor in European politics. Few people realize that the Jurassic system was the chief cause of the Great War.